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FINAL REPORT
DESIGN AND FABRICATION OF THE BRAYTON CYCLE HIGH PERFORMANCE TURBINE RESEARCH PACKAGE

Prepared for

National Aeronautics and Space Administration

Contract NAS3-9427

NOTICE

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Prepared for

National Aeronautics and Space Administration

by

AiResearch Manufacturing Company of Arizona

February 14, 1968

Contract NAS3-9427

Technical Management
NASA Lewis Research Center
Cleveland, Ohio

Space Power Systems Division
James H. Dunn

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

ABSTRACT

AiResearch Manufacturing Company of Arizona designed, fabricated, performed acceptance testing and delivered to the NASA a Brayton-Cycle turbine research package under NASA Contract NAS3-9427.

The research package is aerodynamically identical to the turbine used in the NASA Brayton Rotating Units (BRU) to be delivered under the same contract. This turbine research package will be utilized at the NASA Lewis Research Center for complete component performance evaluation.

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LIST OF SYMBOLS & DEFINITIONS

SYMBOLS

a	=	Velocity of sound = $\sqrt{\gamma gRT}$, ft/sec
Δh	=	Specific work, btu/lb
g	=	Gravitational constant, 32.174 ft/sec^2
H	=	Isentropic specific work (based on turbine inlet total-to-rotor exit static pressure ratio), ft-lb/lb
N	=	Turbine speed, rpm
Ns	=	Specific speed, $NQ^{1/2}/(H)^{3/4}$
p	=	Pressure, psia
Q	=	Volume flow (based on rotor exit static conditions of pressure and temperature), ft^3/sec.
r	=	Radius, ft
R	=	Gas constant, ft-lb/(lb-$^\circ$R)
Re	=	Reynolds number, $\frac{w}{\mu r_t}$
T	=	Absolute temperature, $^\circ$R
μ	=	Viscosity, lb/(ft-sec)
U	=	Blade velocity, ft/sec
V	=	Absolute gas velocity, ft/sec
V_j	=	Ideal jet speed (based on turbine inlet total-to-rotor exit static pressure ratio), $\sqrt{2gH}$
w	=	Weight flow, lb/sec
W	=	Relative gas velocity, ft/sec
Z	=	Axial distance from reference plane, inches
α	=	Absolute gas flow angle measured from axial direction, degrees
β	=	Relative gas flow angle measured from axial direction, degrees
γ	=	Ratio of specific heats

LIST OF SYMBOLS & DEFINITIONS

SYMBOLS

ν = Blade-to-jet speed ratio (based on rotor inlet tip speed), U_t/V_j.

SUBSCRIPTS:

u = Tangential component

t = Tip

1 = Station at turbine scroll inlet flange

SUPERSCRIPTS:

$'$ = Absolute total state

FINAL REPORT
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1. INTRODUCTION

This report, submitted by the AiResearch Manufacturing Company of Arizona, a division of the Garrett Corporation, describes the design, fabrication, inspection and acceptance testing of the NASA Brayton-Cycle turbine research package.

The research package consists of a 4.97-inch diameter turbine wheel and shaft mounted on ball bearings and the associated mounting hardware. The aerodynamic passages of the turbine and nozzle-scroll assembly are identical to the turbine in the Brayton Rotating Units (BRU) to be delivered under the same contract.

The turbine research package underwent a mechanical integrity spin-up test as reported in the acceptance test section of this report. Subsequently, the research package was shipped to the NASA-Lewis Research Center in accordance with the contract requirements.

2. DETERMINATION OF DESIGN CONDITIONS

During the preliminary design phase of the BRU program, system studies were performed to determine trends toward establishing the optimum BRU configuration and its corresponding design points at three representative power levels--2.25 kw_e, 6.0 kw_e, and 10.5 kw_e net electrical output. Extensive parametric analysis evolved a system design which yielded high cycle efficiency and conditions favorable to the BRU throughout the 2.25 kw_e to 10.5 kw_e power range.

The turbine design conditions resulting from the analysis at the reference design power level of 6.0 kw_e are as follows:

Working fluid	XeHe mixture, equivalent molecular weight = 83.8
Turbine inlet pressure (total)	25.0 psia
Turbine inlet temperature (total)	2060°R
Turbine inlet total-to-exhaust diffuser exit static pressure ratio	1.76
Turbine specific speed	74.2
Turbine static efficiency (Uncorrected for Reynold's number effect) (Based on turbine inlet total-to-exhaust diffuser exit static pressure ratio)	87.5 percent
Turbine inlet mass flow rate	0.756 lb/sec
Turbine rotating speed	36,000 rpm

3. TURBINE DESIGN

3.1 Aerodynamic Design Approach

An investigation was conducted for utilizing a scaled version of the 6.02-inch diameter turbine delivered to the NASA under Contract NAS3-2778.

The method of analysis used to arrive at the estimated performance was based on the results of an AiResearch-developed computer program. This program was written to predict the off-design performance of radial inflow turbines with or without an exhaust diffuser, on a one-dimensional basis, given certain geometrical, gas thermodynamic properties, and aerodynamic input constants. These constants were adjusted so that the predicted and measured performance of the 6.02 inch diameter wheel, as tested in argon at a Reynolds number of approximately 2×10^5, agreed as closely as possible.

A new wheel tip diameter was computed from the design point parameters such that it would operate at a blade-to-jet speed ratio of 0.707, which is also the point at which the turbine total-to-total efficiency at the rotor exit is a maximum. The resultant scale factor was 0.825.

New input was prepared and the scaled wheel was run with XeHe gas properties. This resulted in a turbine which had a total-to-static efficiency at the diffuser exit of 87.4 percent at the design total-to-static pressure ratio of 1.75 but with a turbine corrected inlet mass flow of 1.36 pounds per second instead of the required flow of 0.876 pound per second.

At this point three possible approaches were considered for attaining the required mass flow. These were:

(1) To recontour the wheel to the 64.5 percent streamline.

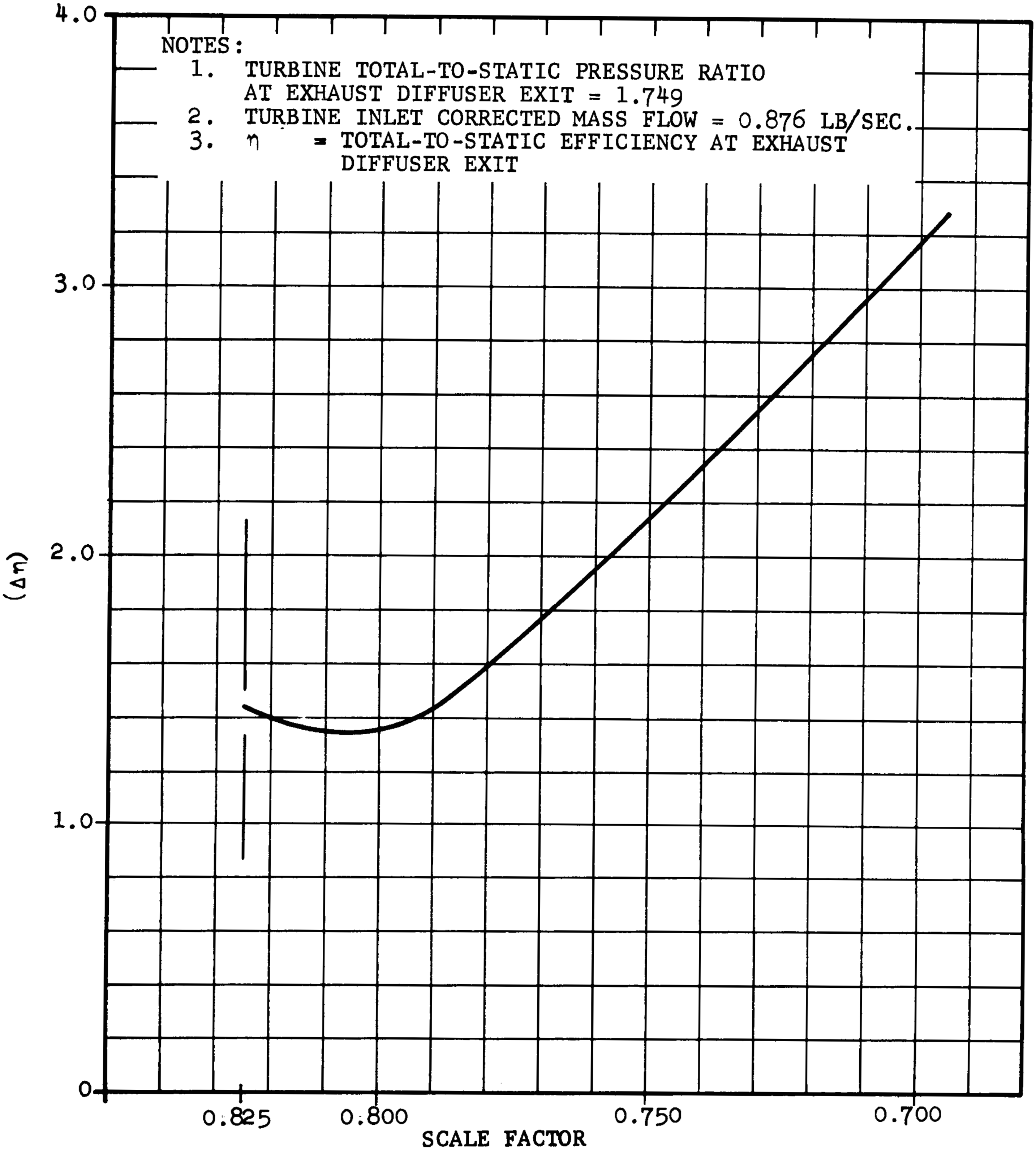
(2) To close the nozzle area down to 64.5 percent flow.

(3) To further scale-down the turbine such that it would pass the required flow, realizing that the blade-to-jet speed ratio would be reduced.

The efficiency drop associated with approach (1) was judged to be of such magnitude as to preclude the attainment of the design objectives. Therefore, only the latter two approaches were deemed practical.

Using the turbine off-design computer program, determinations were made of the incremental changes in turbine efficiency and mass flow due to changes in turbine nozzle area, holding the turbine scale factor to the value corresponding to a blade-to-jet speed ratio of 0.707. Also, the incremental change in turbine efficiency and mass flow due to changes in scale factor, which resulted in operation at blade-to-jet speed ratios less than 0.707, were likewise determined.

The results of various combinations of scale factor and turbine nozzle area which met the design flow requirements at the design turbine pressure ratios are shown in Figure 1, where the sum total of the individual turbine efficiency decrements (those due to nozzle area change and those due to changes in blade-to-jet speed ratios) are plotted as a function of the scale factor. The point of minimum loss lies within a range of a scale factor value of 0.80 to 0.81.



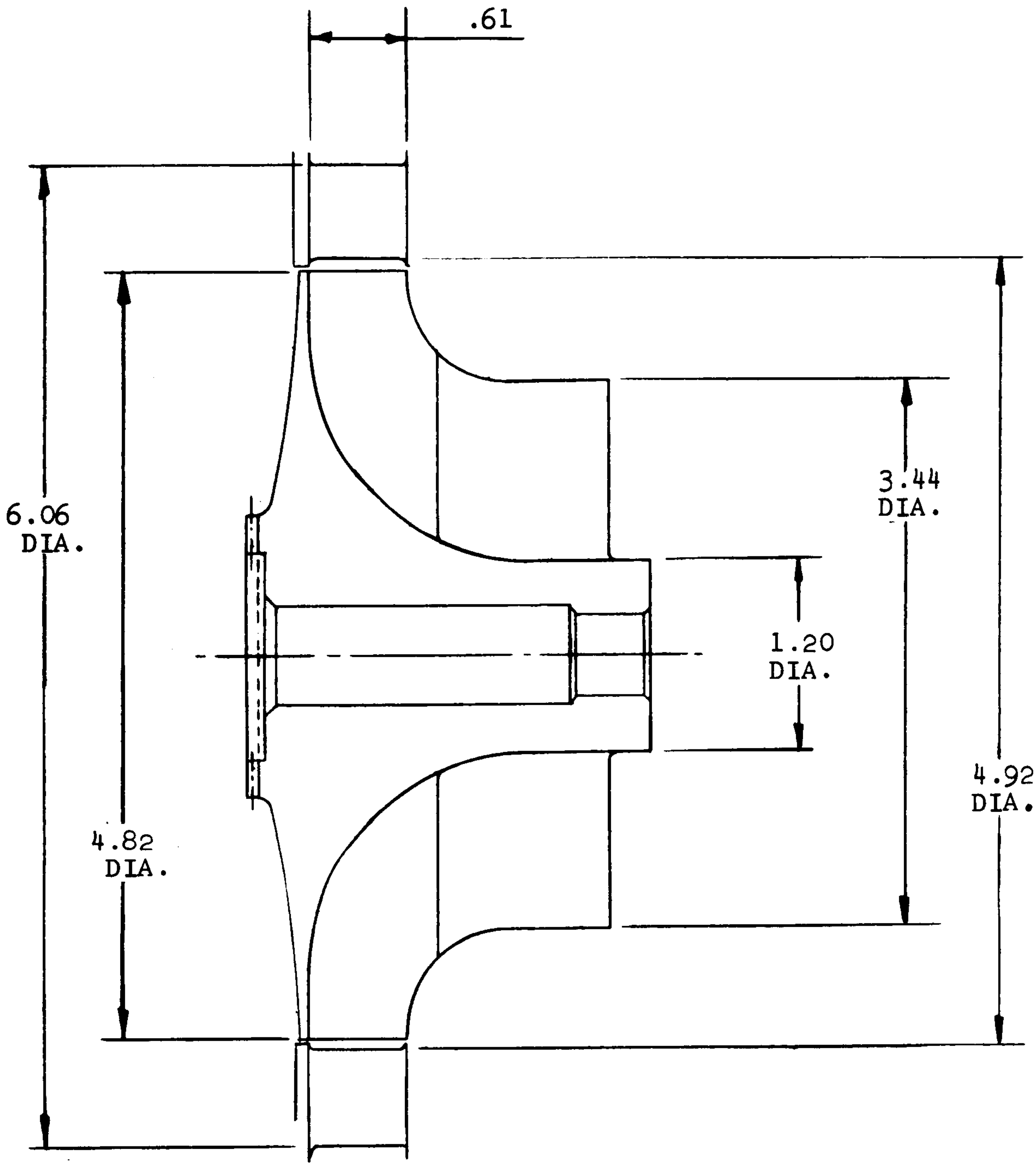
COMBINED EFFICIENCY DECREMENTS
DUE TO CHANGES OF NOZZLE
AREA AND BLADE-TO-JET SPEED RATIO

FIGURE 1

A scale factor of 0.80 and a nozzle area of 1.815 square inches was selected on the basis of the above curve. The resultant turbine and its velocity vector diagrams are shown in Figures 2 and 3. The turbine performance for the design turbine corrected speed is shown in Figure 4. The turbine total-to-static efficiency at the turbine exhaust diffuser exit and turbine inlet corrected mass flow are plotted as a function of the turbine total-to-static pressure ratio at the turbine exhaust diffuser exit. The turbine efficiency at design pressure ratio is 0.860. This efficiency level does not include any correction for Reynolds number effects.

Commonly accepted compressor practice assumes that the losses vary inversely as the ratio of Reynolds number to the 0.2 power. However the turbine flow function is an accelerating one by nature and the boundary layer is not subjected to an adverse pressure gradient such as exists in a compressor. Hence it was decided, in view of the above, and based on test data and information from the literature, to penalize the turbine total-to-total efficiency at the rotor exit by using an exponent of 0.15. The diffuser losses, since the flow is decelerating, were assumed to vary as the previously mentioned compressor losses.

The resultant turbine total-to-static efficiency, penalized for Reynolds number effects, is 0.839 at the design total-to-static pressure ratio at the diffuser exit. No attempt was made to calculate the effect of Reynolds number on turbine mass flow. It should be mentioned at this time that a possible improvement in the efficiency level of this



BRU TURBINE SCALED FROM 6.02-IN.
DIAMETER NASA TURBINE

FIGURE 2

A33196

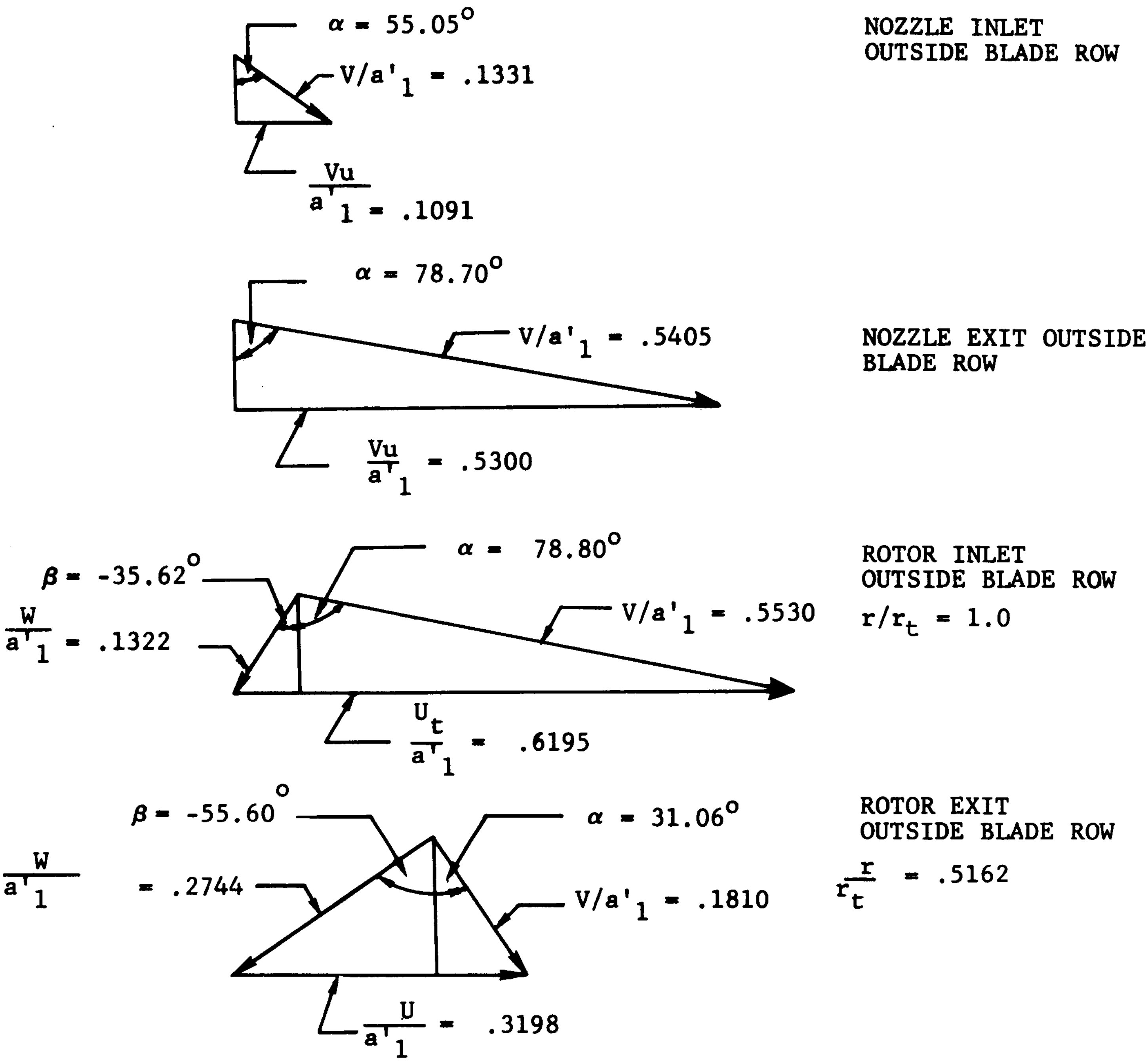


FIGURE 3

VELOCITY VECTOR DIAGRAMS
SCALED DOWN 6.02 IN. DIAMETER TURBINE

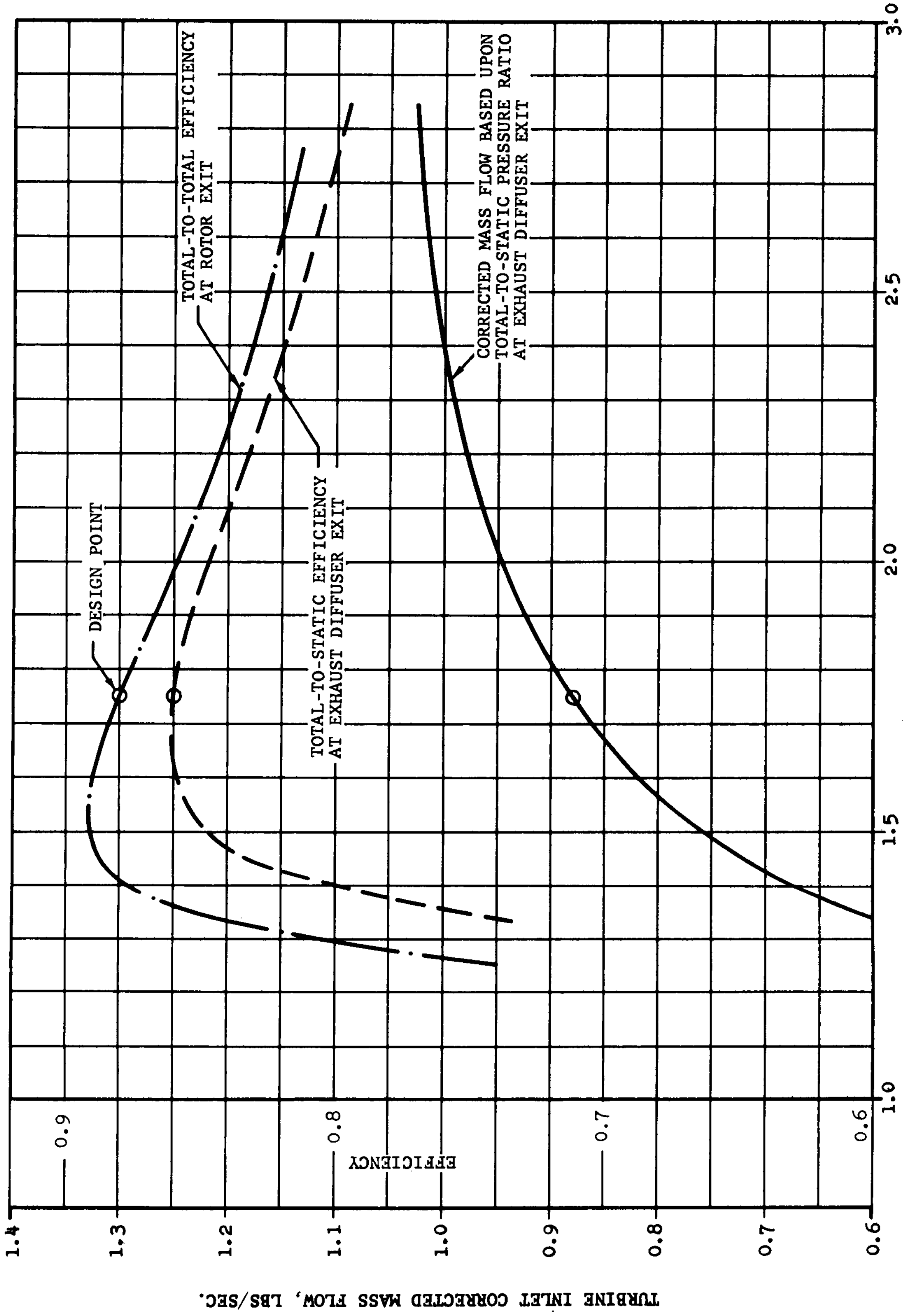


FIGURE 4

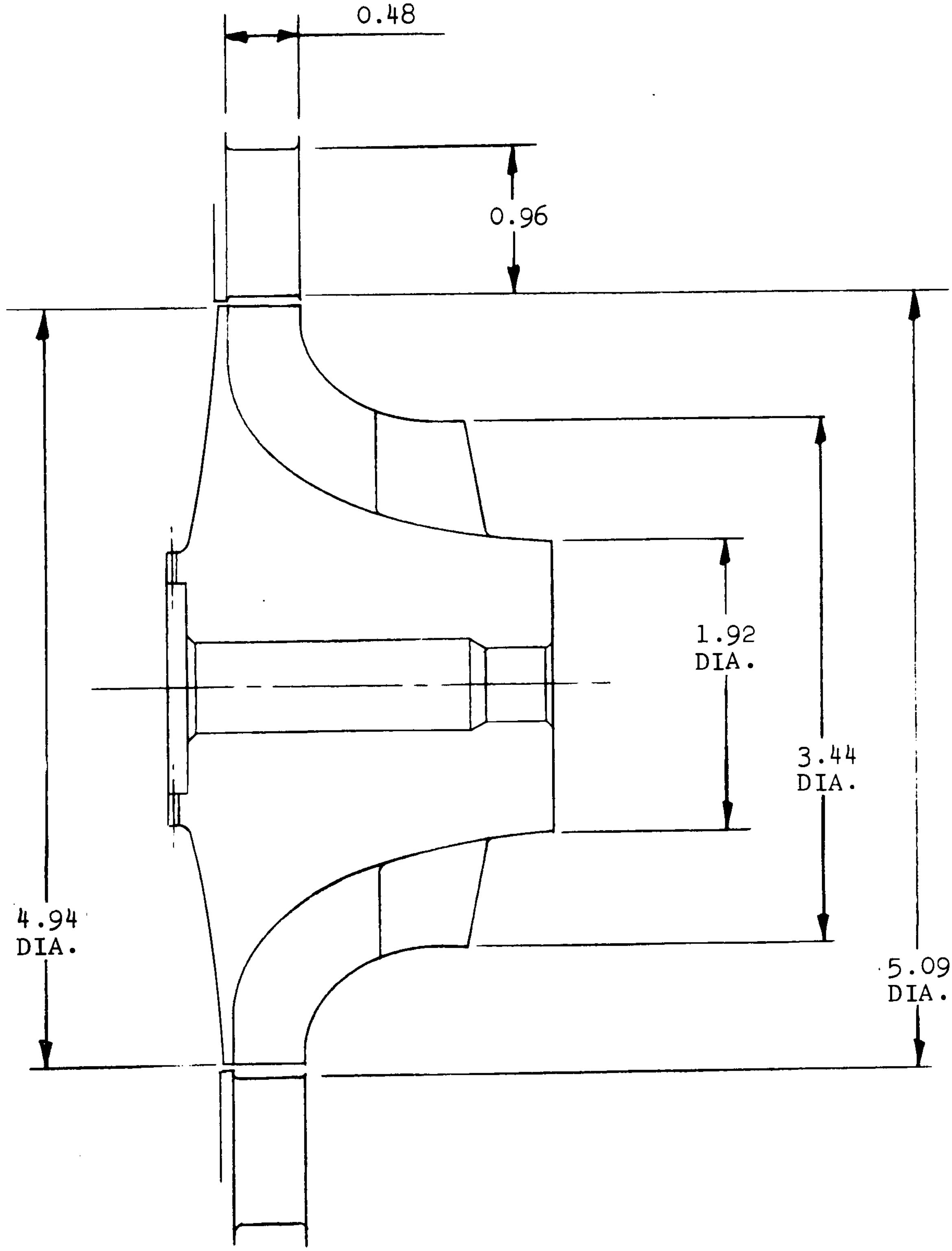
ESTIMATED TURBINE PERFORMANCE
OF SCALED-DOWN 6.02 INCH DIAMETER TURBINE

turbine might be obtained by extending the exducer trailing edge. This would tend to minimize the loss due to the exit swirl.

As part of the turbine preliminary design study a new turbine design was investigated. The reason for considering the new turbine was that the 6.02 inch diameter wheel from which the previous design was scaled, was optimized for operation at a design specific speed of 100. Since the BRU turbine design parameters define a turbine operating at a specific speed of 75, it was concluded that better turbine performance might be attained by optimizing new geometry for the lower specific speed.

Figure 5 shows the resultant preliminary turbine geometry for the new design. Figure 6 presents the preliminary velocity vector diagrams. The high hub diameter of this turbine has the advantage that it can more easily accommodate a larger number of blades or a larger splitter vane length than the scaled design. This might be necessary in order to reduce the blade loading such that the hub pressure surface velocity would not become negative.

The estimated performance of the new turbine design without Reynolds number effects is shown in Figure 7. The turbine total-to-total efficiency at the rotor exit is 90 percent which is consistent with the measured performance of the NASA 6.02 inch diameter turbine wheel when operating at Reynolds numbers in excess of 2×10^5. This is considered, however, to be conservative, not only for the reason previously stated but mainly for the reason that the above



BRU TURBINE - PRELIMINARY DESIGN

FIGURE 5

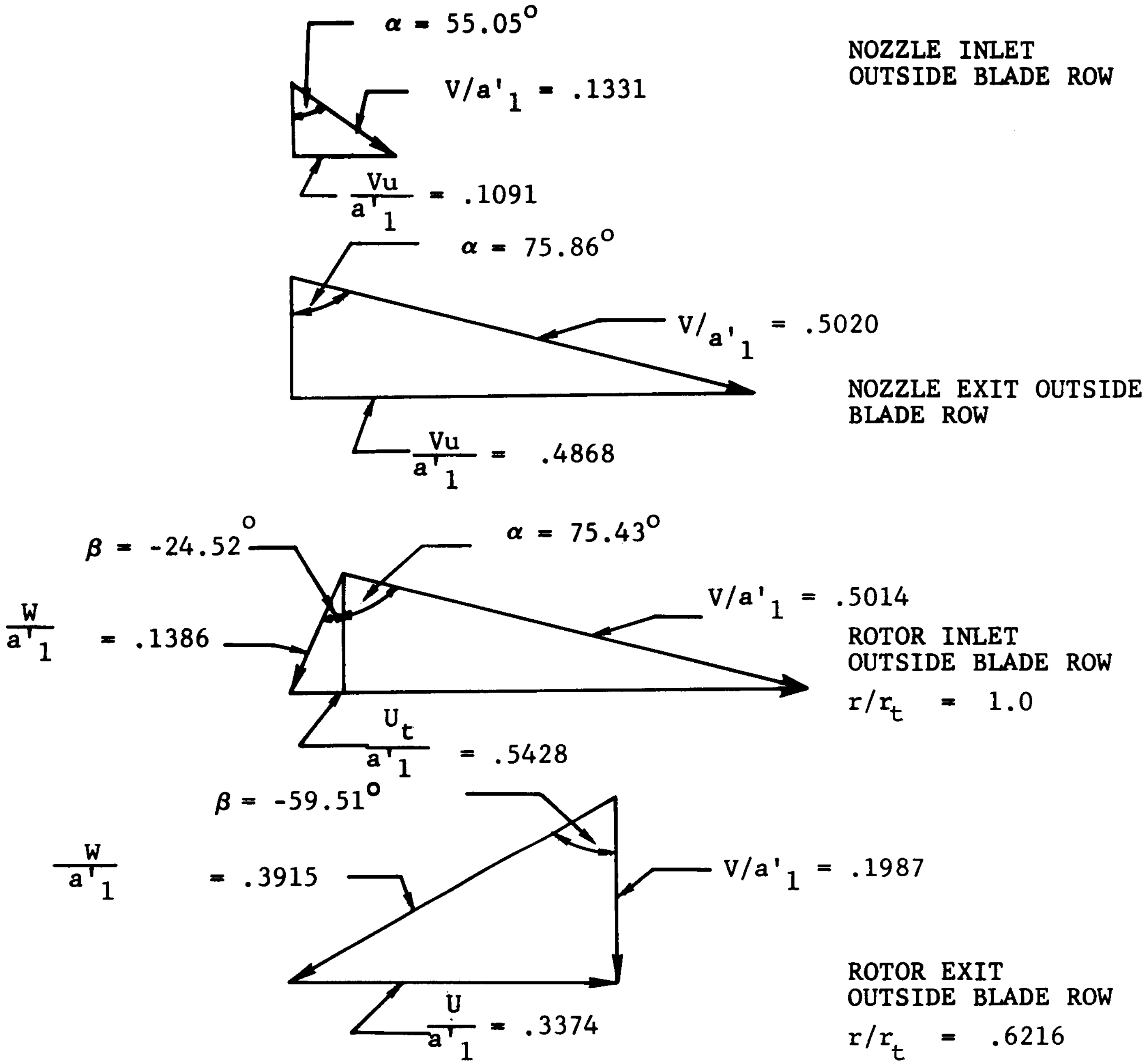
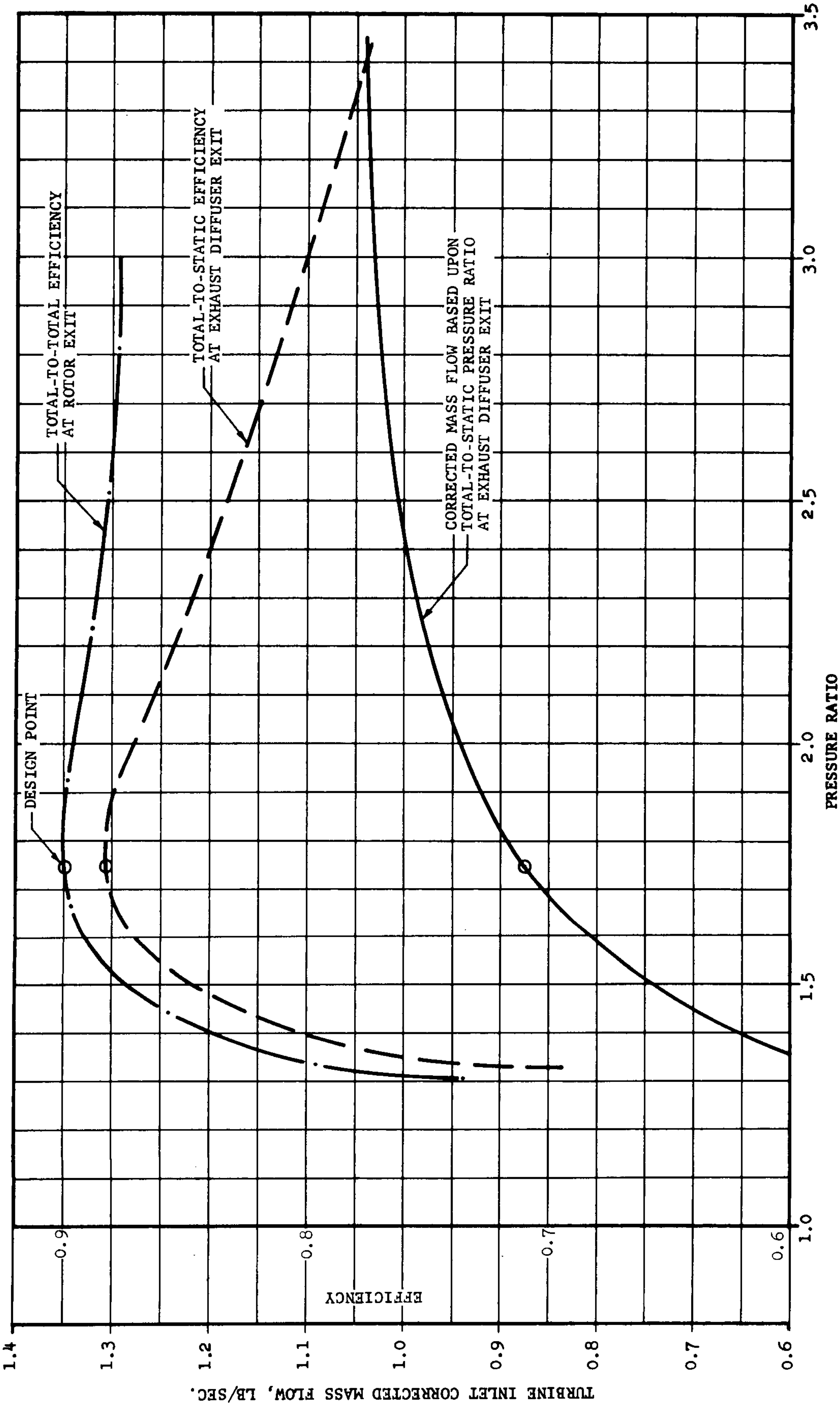


FIGURE 6

VELOCITY VECTOR DIAGRAMS
(OUTSIDE BLADE ROW)
PRELIMINARY TURBINE DESIGN



ESTIMATED PERFORMANCE
PRELIMINARY TURBINE DESIGN

FIGURE 7

referenced turbine was designed three years ago without the advantages of the new design techniques which have since evolved.

The efficiency of the new turbine design was penalized in the same manner as that for the previously discussed scaled-down wheel. The result was a turbine total-to-static efficiency of 0.860 at the design total-to-static pressure ratio (turbine inlet to diffuser exit).

3.2 Final Aerodynamic Design

Based upon the findings of the preliminary turbine design study of Section 3.1, it was decided to pursue the approach of designing a new turbine for the Brayton Rotating Unit.

Pertinent design parameter information is tabulated below:

(a)	Total-to-total efficiency (uncorrected for Reynolds number effect) at rotor exit (based on turbine inlet total-to-rotor exit total pressure ratio).	.8937
(b)	Turbine inlet total-to-rotor exit total pressure ratio.	1.740
(c)	Total-to-static efficiency (uncorrected for Reynolds number effect) at rotor exit (based on turbine inlet total-to-rotor exit static pressure ratio).	.8476
(d)	Turbine inlet total-to-rotor exit static pressure ratio.	1.800
(e)	Total-to-total efficiency (uncorrected for Reynolds number effect) at diffuser exit. (Based on turbine inlet total-to-exhaust diffuser exit total pressure ratio).	.8858

(f)	Turbine inlet total-to-exhaust diffuser exit total pressure ratio	1.749
(g)	Total-to-static efficiency (uncorrected for Reynolds number effect). (Based on turbine inlet total-to-exhaust diffuser exit static pressure ratio).	.8750
(h)	Turbine inlet total-to-exhaust diffuser exit static pressure ratio	1.763
(i)	Blade-to-jet speed ratio $\nu = \frac{U_t}{V_j}$	.690
(j)	Actual specific work, Δh, btu/lb	21.67
(k)	Weight flow, w, lb/sec	.7484
(l)	Specific speed, $Ns = NQ^{1/2}/(H)^{3/4}$	76.20
(m)	Turbine speed, N, rpm	36,000
(n)	Reynolds number, $Re = \frac{w}{\mu_1 r_t}$	76,250
(o)	Inlet total temperature, T_1' °R	2060
(p)	Inlet total pressure, p_1', psia	25.0
(q)	Working fluid = XeHe mixture, molecular weight	83.8
(r)	Specific heat, Cp, btu/(lb-°R)	.05925
(s)	Gas constant, R, ft-lb/(lb-°R)	18.44
(t)	Ratio of specific heats, γ	5/3
(u)	Number of blades	11
(v)	Number of splitters	11

The temperatures listed on Table 1 have been revised in order to be consistent with the aforementioned efficiencies and the pressures listed on Table 1. However, a temperature drop between the rotor inlet and exit which is calculated from the velocity diagrams will be larger than that shown on Table 1 by the amount assumed for the rotor windage or disc friction plus rotor shroud clearance losses.

TABLE 1

TURBINE PRESSURE AND TEMPERATURE DISTRIBUTION

	Total Pressure psia	Static Pressure psia	Total Temperature °R
Scroll inlet	25.00	24.95	2060
Stator inlet	24.90	24.56	2060
Stator exit	24.78	19.57	2060
Rotor inlet	24.67	19.28	2060
Rotor exit	14.37	13.89	1694
Diffuser exit	14.29	14.18	1694

The final turbine geometry including the exhaust diffuser is shown in Figure 8 and the turbine velocity diagrams are shown in Figures 9 and 10. The rotor velocity diagrams are presented for the midpoint of the three stream tubes as indicated in Figure 8. The blade trailing edge extension, as shown, provides enough blade length so that the rotor blade trailing edge may be tailored – based on data from rotor exit survey measurements – by machining to the proper shape so as to produce – at the rotor exit – a nearly zero tangential component of absolute velocity. Note that the rotor exit velocity diagrams are for the point where the theoretical computations indicated that the rotor exit tangential component of absolute velocity would be nearly zero. This occurs at a Z dimension of 1.556 which is 0.209 of an inch in from the rotor trailing edge as noted in Figure 8a and 8b.

3.3 Turbine-Wheel Thermal Stress Analysis

A temperature and thermal stress analysis was performed on the BRU turbine wheel. BRU steady-state operating conditions for turbine inlet temperature (2060°R) and speed (36,000 rpm) were utilized for the analysis. Temperatures obtained from the complete BRU thermal analysis were used to set the boundary conditions.

Figure 11 presents the steady-state blade and disk temperature distribution in the turbine wheel and attachment sleeve. By use of this temperature distribution, the combined thermal and centrifugal stresses were calculated for the turbine wheel operating at 36,000 rpm. The resulting radial and tangential stresses are shown in Figures 12 and 13.

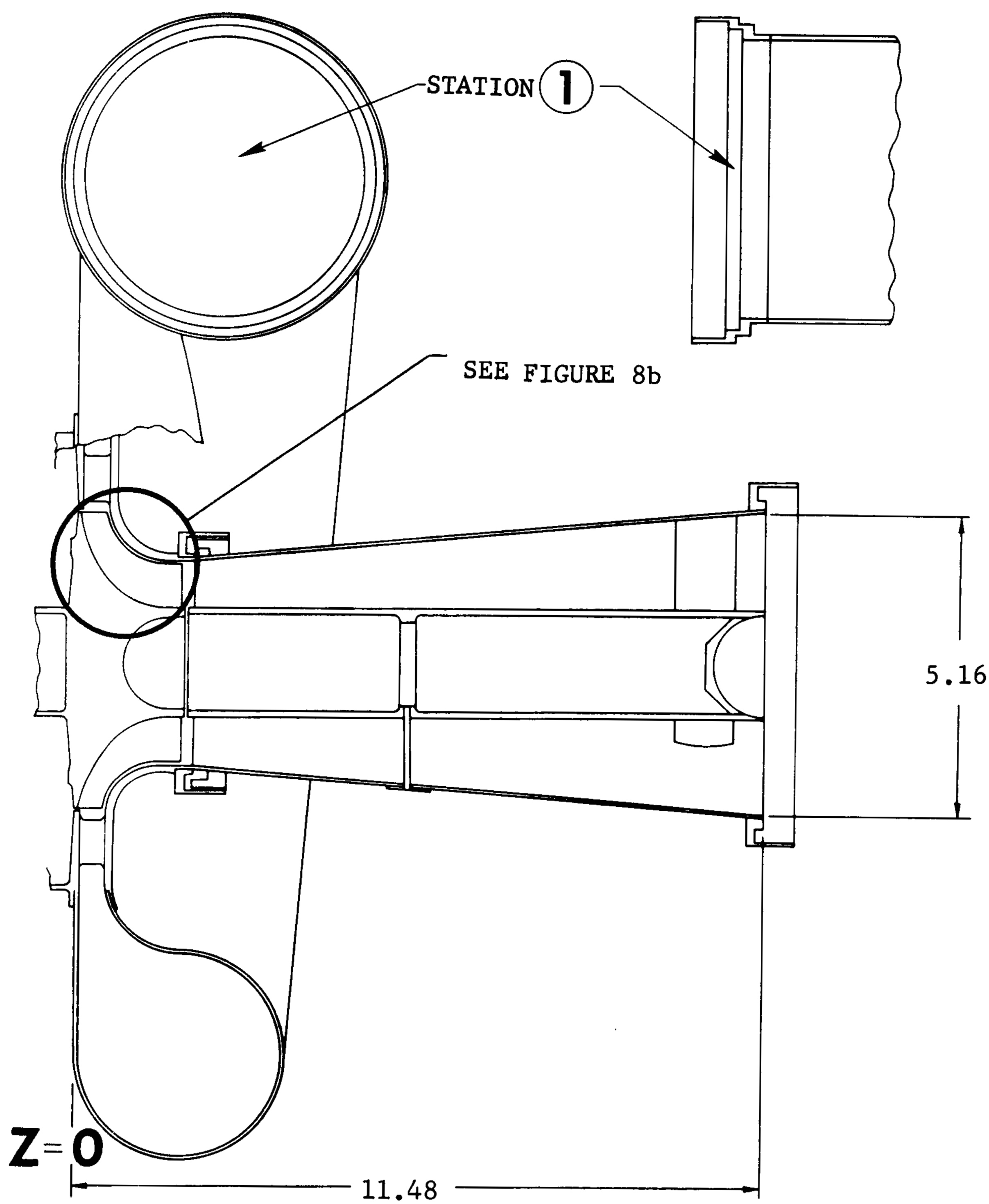


FIGURE 8a
NASA BRU TURBINE PHYSICAL DIMENSIONS
(FINAL TURBINE DESIGN)

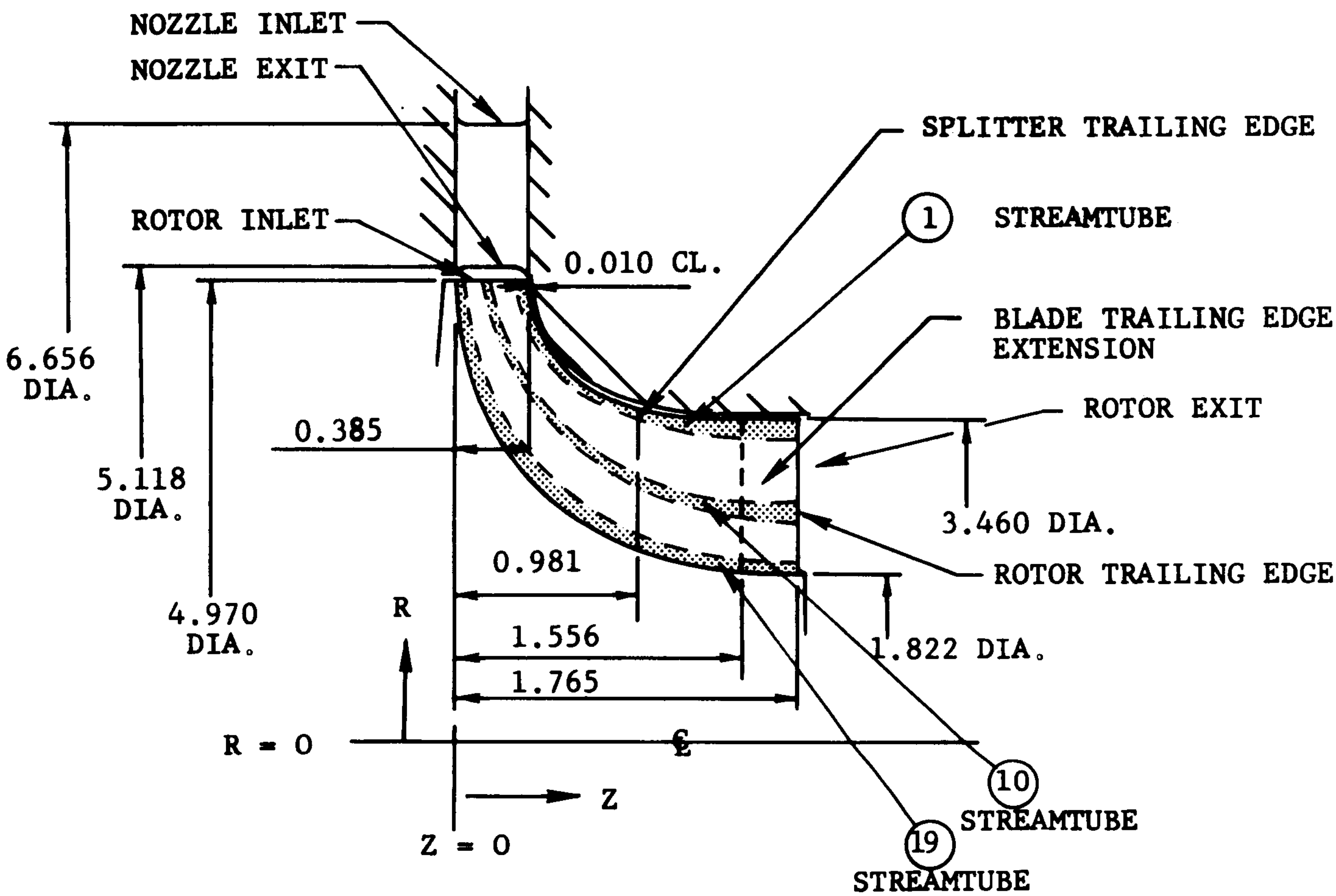
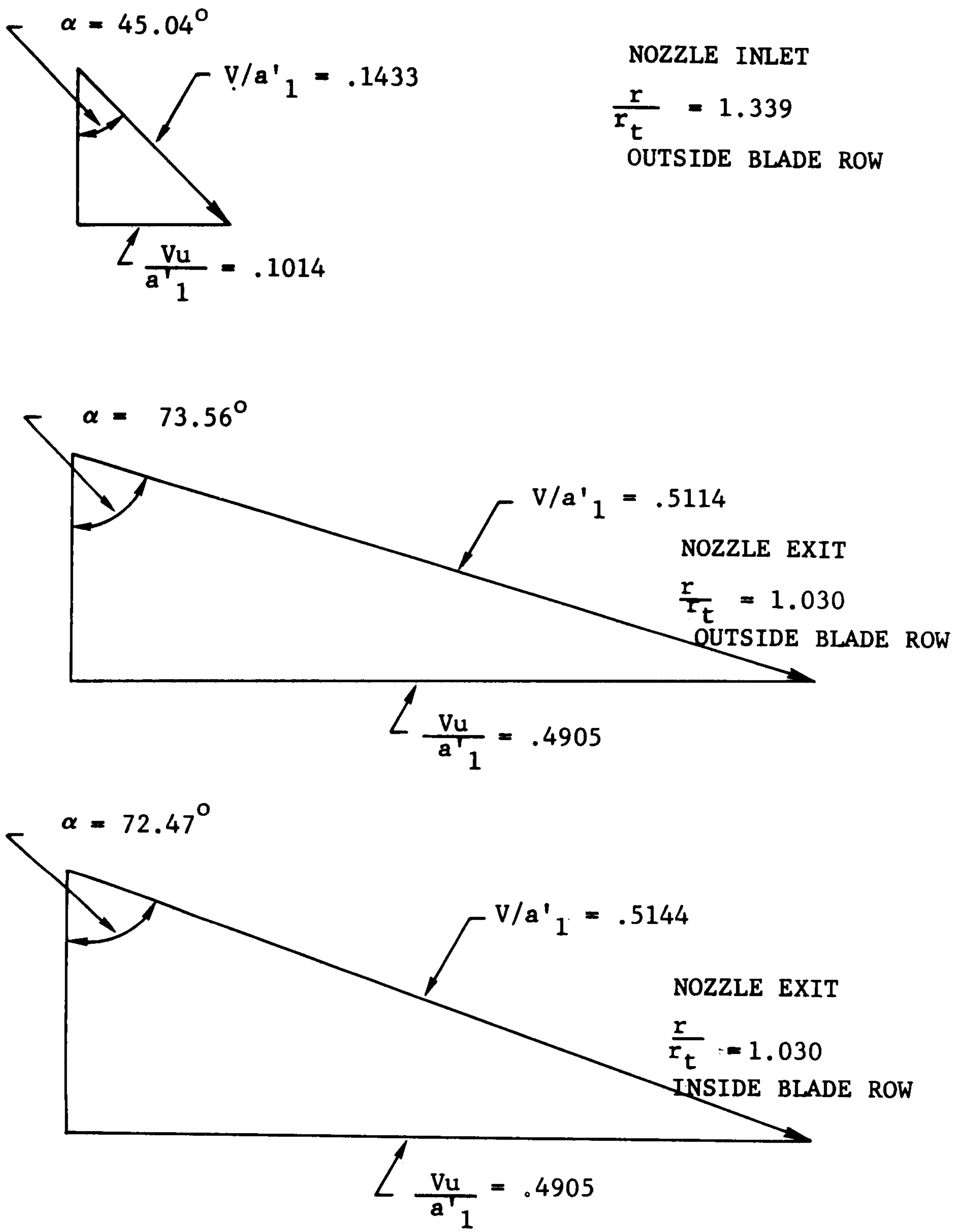


FIGURE 8b

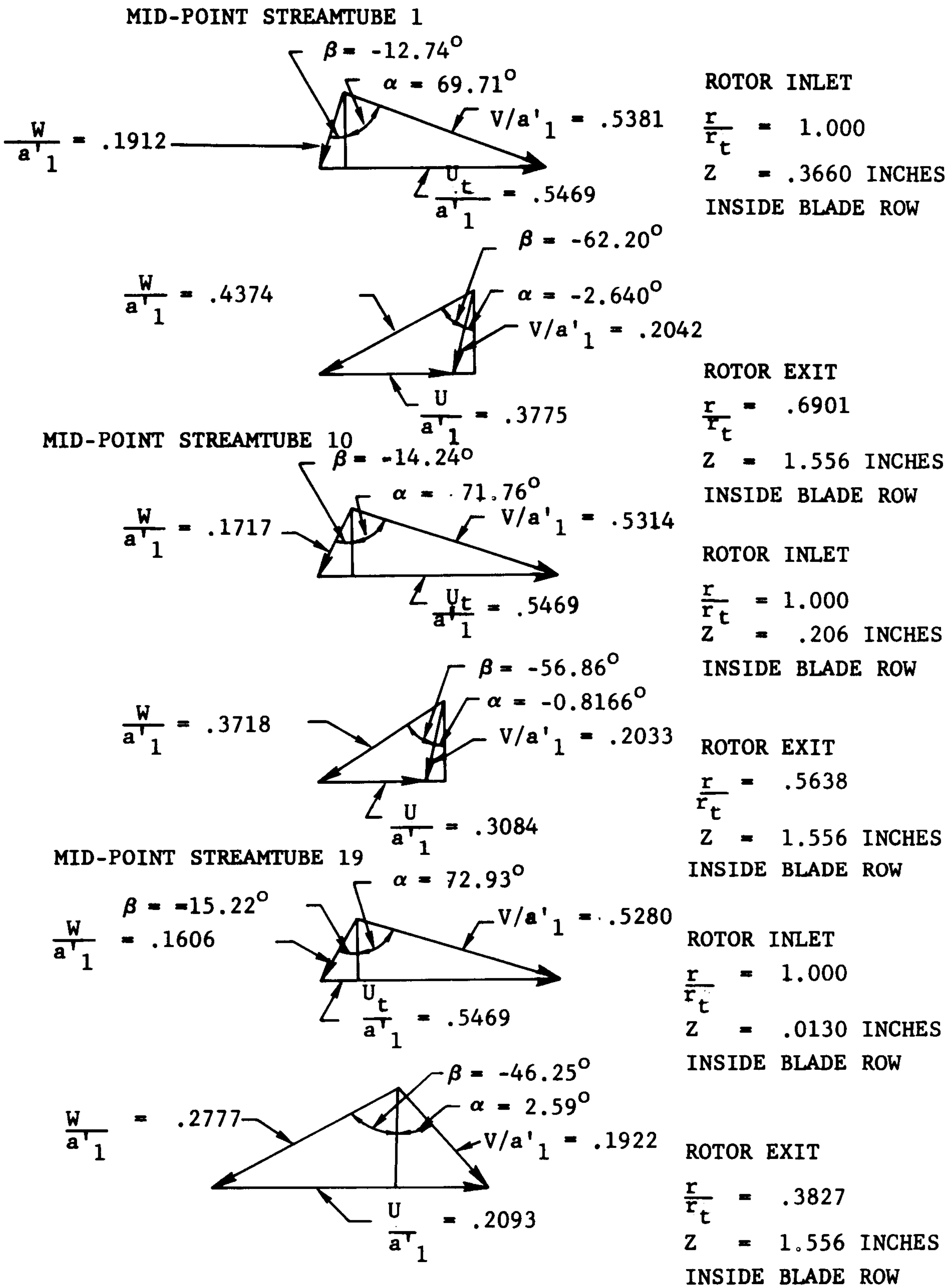
NASA BRU TURBINE PHYSICAL DIMENSIONS
(FINAL TURBINE DESIGN)



NOZZLE EXIT - INSIDE BLADE ROW

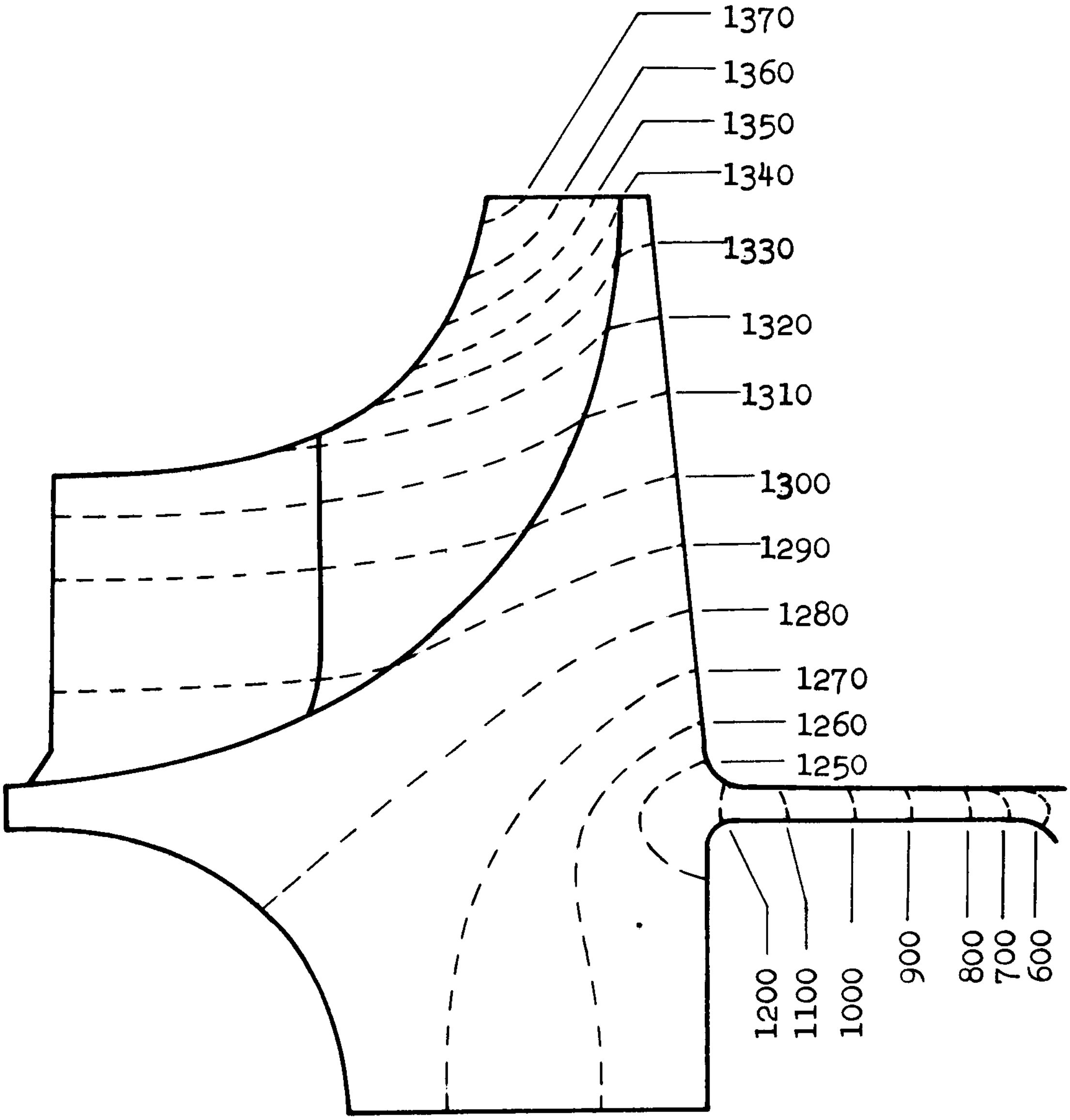
FIGURE 9

NOZZLE VECTOR DIAGRAMS
(FINAL TURBINE DESIGN)



XeHe BRU TURBINE ROTOR VECTOR DIAGRAMS - (INSIDE BLADE ROW)
(FINAL TURBINE DESIGN)

FIGURE 10



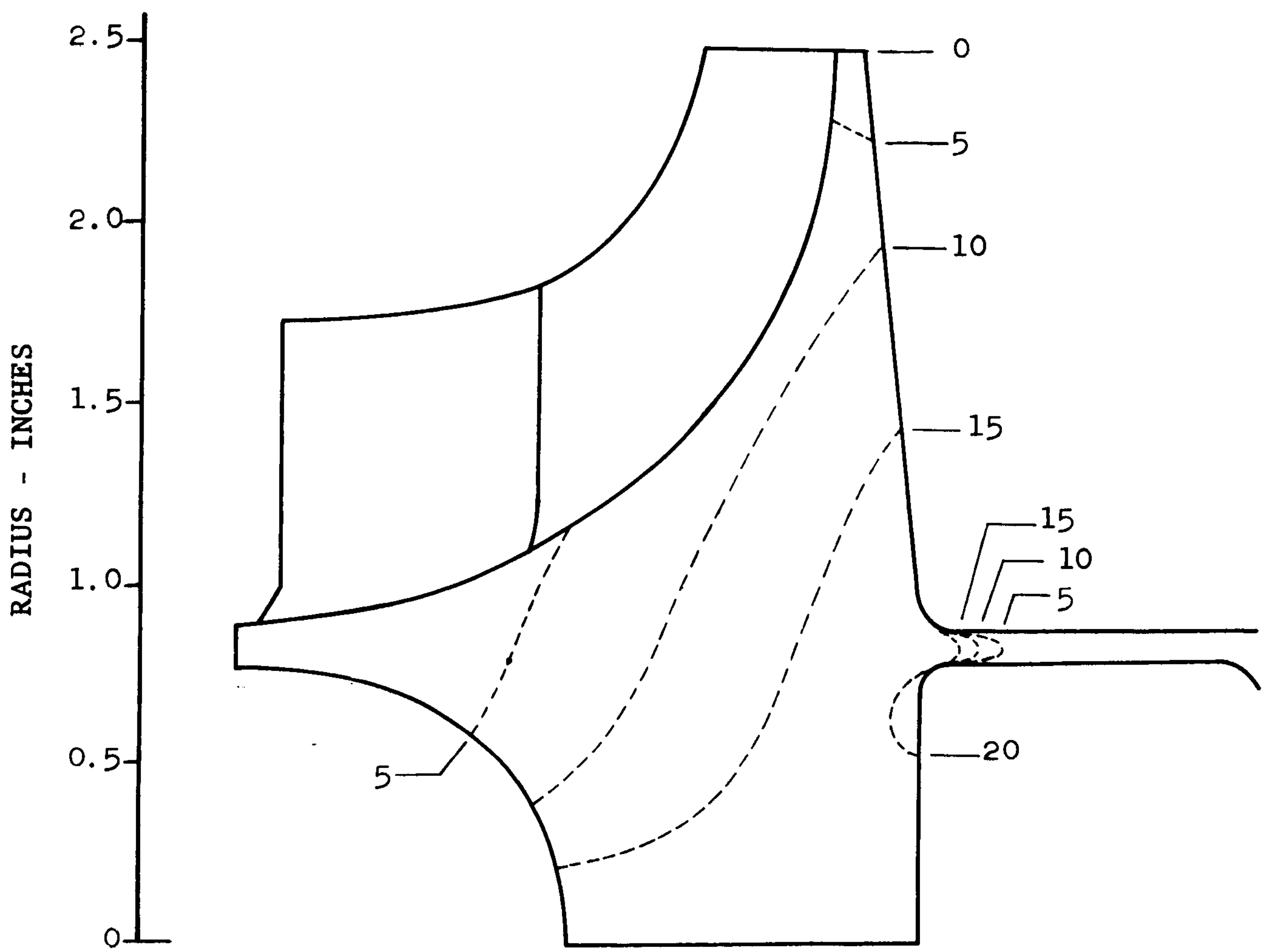
TEMPERATURES - °F
36,000 RPM
6.0 KW

FIGURE 11

STEADY-STATE TEMPERATURE DISTRIBUTION
NASA BRU TURBINE WHEEL

A33456

MAXIMUM BLADE STRESS = 10,000 PSI



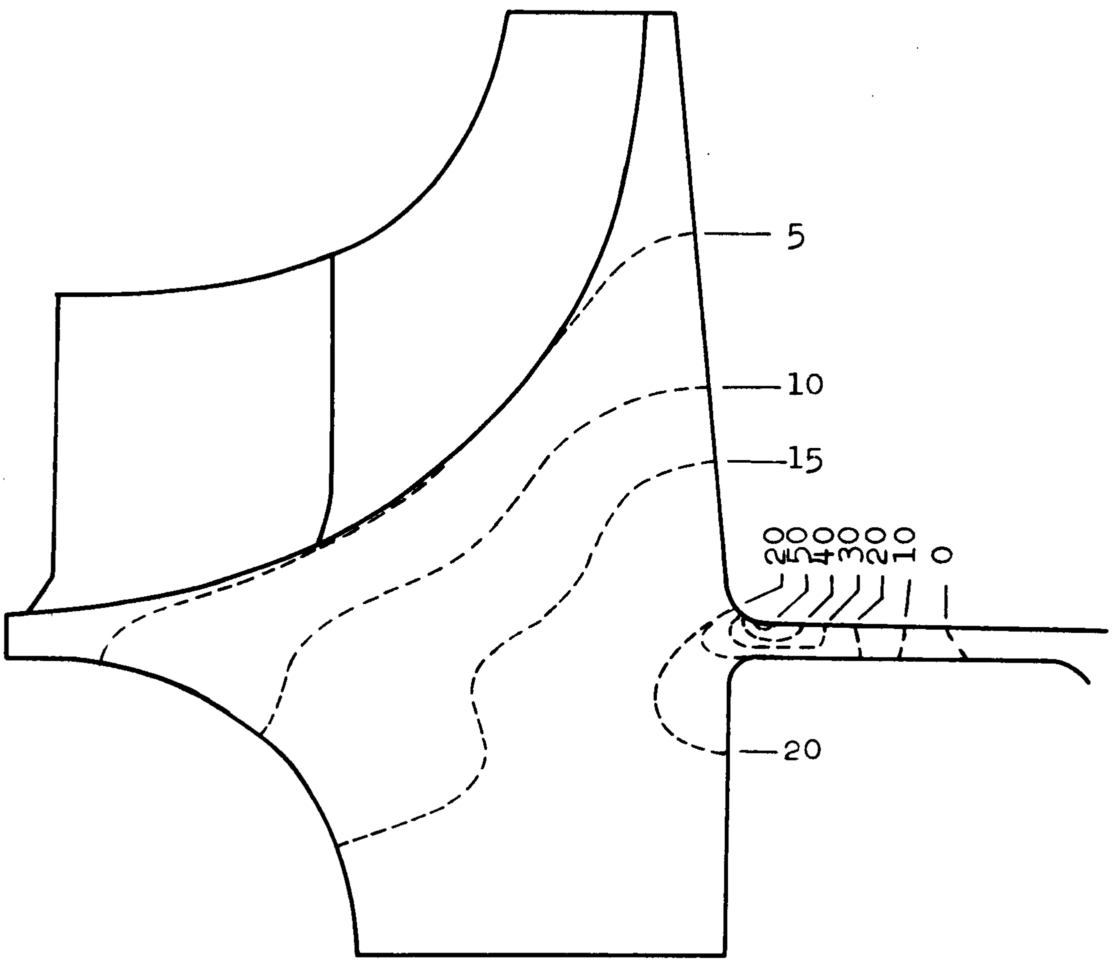
RADIAL STRESS - KSI
36,000 RPM

FIGURE 12

RADIAL STRESS DISTRIBUTION
NASA BRU TURBINE WHEEL

A33457

AVERAGE TANGENTIAL STRESS = 12,400 PSI



TANGENTIAL STRESS - KSI
36,000 RPM

FIGURE 13
TANGENTIAL STRESS DISTRIBUTION
NASA BRU TURBINE WHEEL

Figure 14 presents the equivalent stress distribution in the turbine wheel. Equivalent stress is a plane stress defined by

$$\sigma^2_{\text{EQUIV.}} = \sigma_1^2 - \sigma_1 + \sigma_2^2$$

where σ_1 and σ_2 are the principal stresses in the plane. Yielding occurs when the equivalent stress equals the material yield strength. The principal stresses in the wheel disk are the radial and tangential stresses, axial stresses being small. However, in the attachment sleeve, the axial stresses and the tangential stresses are principal and the radial stresses small. As may be observed from Figure 14, the peak stress occurs at the attachment of the sleeve to the wheel disk. A small amount of localized creep and redistribution of stresses will occur at this area during the 50,000-hour wheel design life.

The maximum radial stress in the blades is calculated to be 10,000 psi, which is lower than the average tangential stress in the disk (12,400 psi). Hence, the stress-rupture life of the wheel is limited by the strength of the disk. The stress-rupture life of the turbine wheel, based upon extrapolated creep-test data for the Inconel 713LC wheel material, is calculated to be in excess of 10^8 hours. Creep at 50,000 hours is negligible.

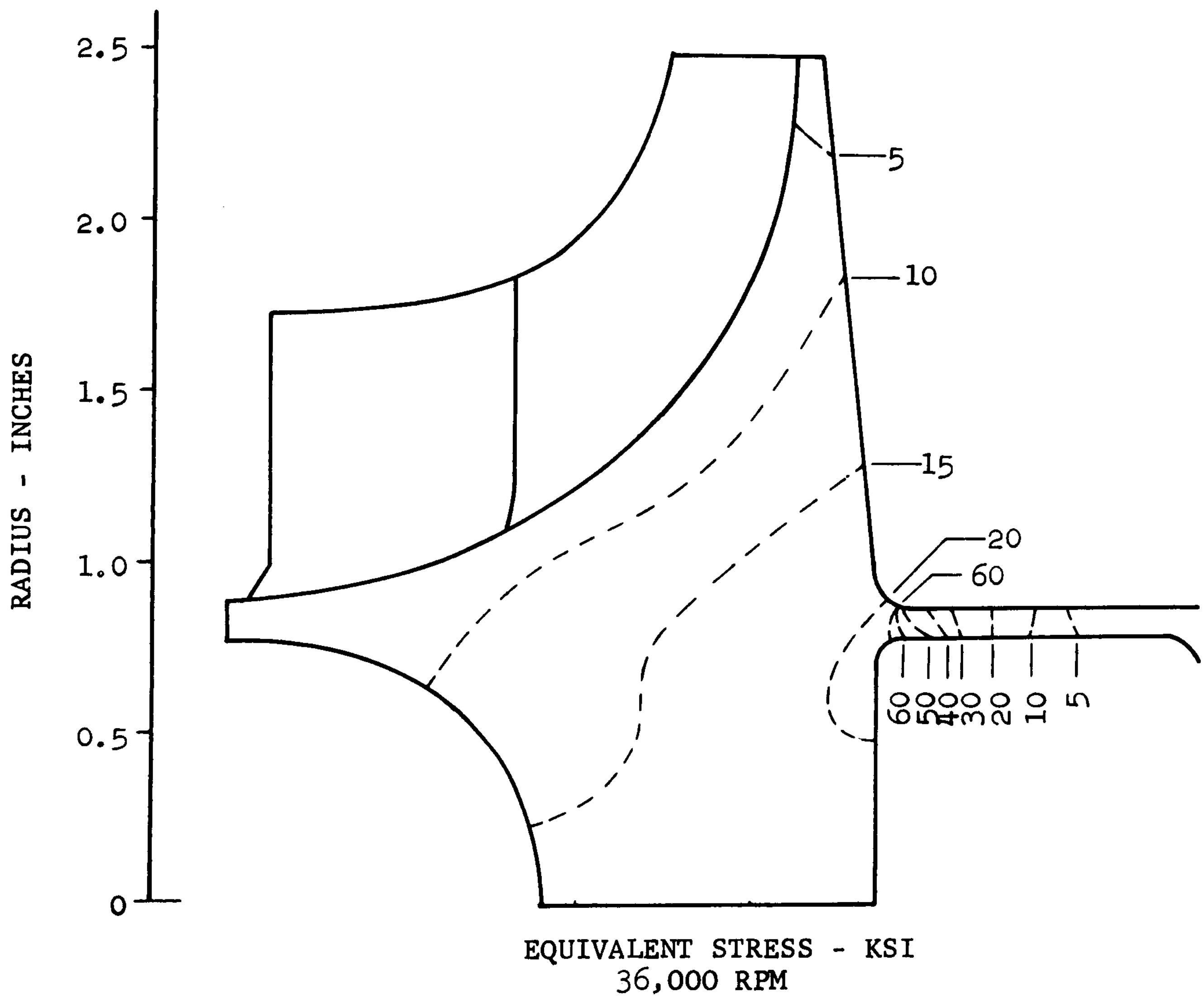


FIGURE 14

EQUIVALENT STRESS DISTRIBUTION
NASA BRU TURBINE WHEEL

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3.4 Critical-Speed Analysis

In order to perform a critical-speed analysis for the turbine research package (Figure 15), the operating speed range for performance testing had to be determined. Equivalent pressure ratios were calculated from the equivalent specific work in argon and air, and the assumption of no change in efficiency when argon or air is used as the working fluid in lieu of the Xenon-helium mixture. Rotative speeds were also calculated. Values of turbine inlet total temperature equal to 700°R, specific heat ratio equal to 5/3 for argon and 7/5 for air, gas constant equal to 38.63 ft-lb/(lb-°R) for argon and 53.34 ft-lb/(lb-°R) for air were used in the computations. The computed values of speed and pressure ratio are given below:

Fluid	Pressure Ratio (Turbine inlet total-to-diffuser exit static)	Rotative Speeds
Argon	1.763	30,394 rpm
Air	1.662	34,461 rpm

Selection of the speed range was coordinated with the cognizant personnel at the NASA-Lewis Research Center.

The elastic and mass models of the rotating assemblies used in the critical-speed analyses are shown in Figure 16. As can be noted, the balanced flexible coupling was included in the elastic and mass models. In addition, the Contractor-selected drive turbine, to be used for the acceptance testing of the research package, was included to determine whether or not the flexible coupling arrangement would significantly influence the rigid-body critical speeds of the research package.

The analysis for the resilient-bearing mounting system led to a resiliently mounted bearing at the turbine and a rigidly mounted rear bearing. The critical speeds of the turbine package rotating assembly for such a mounting arrangement are shown in Figure 17 as a function of the turbine bearing resilient-mount spring rate. Choice of a 30,000 ppi resilient mount at the turbine end will permit performance testing over the anticipated speed range of 18,250 to 36,500 rpm without encountering rigid-body critical speeds. The rotor bending mode critical is shown to be 90,000 rpm. The turbine package bearing loads for the anticipated operating range are shown in Figure 18.

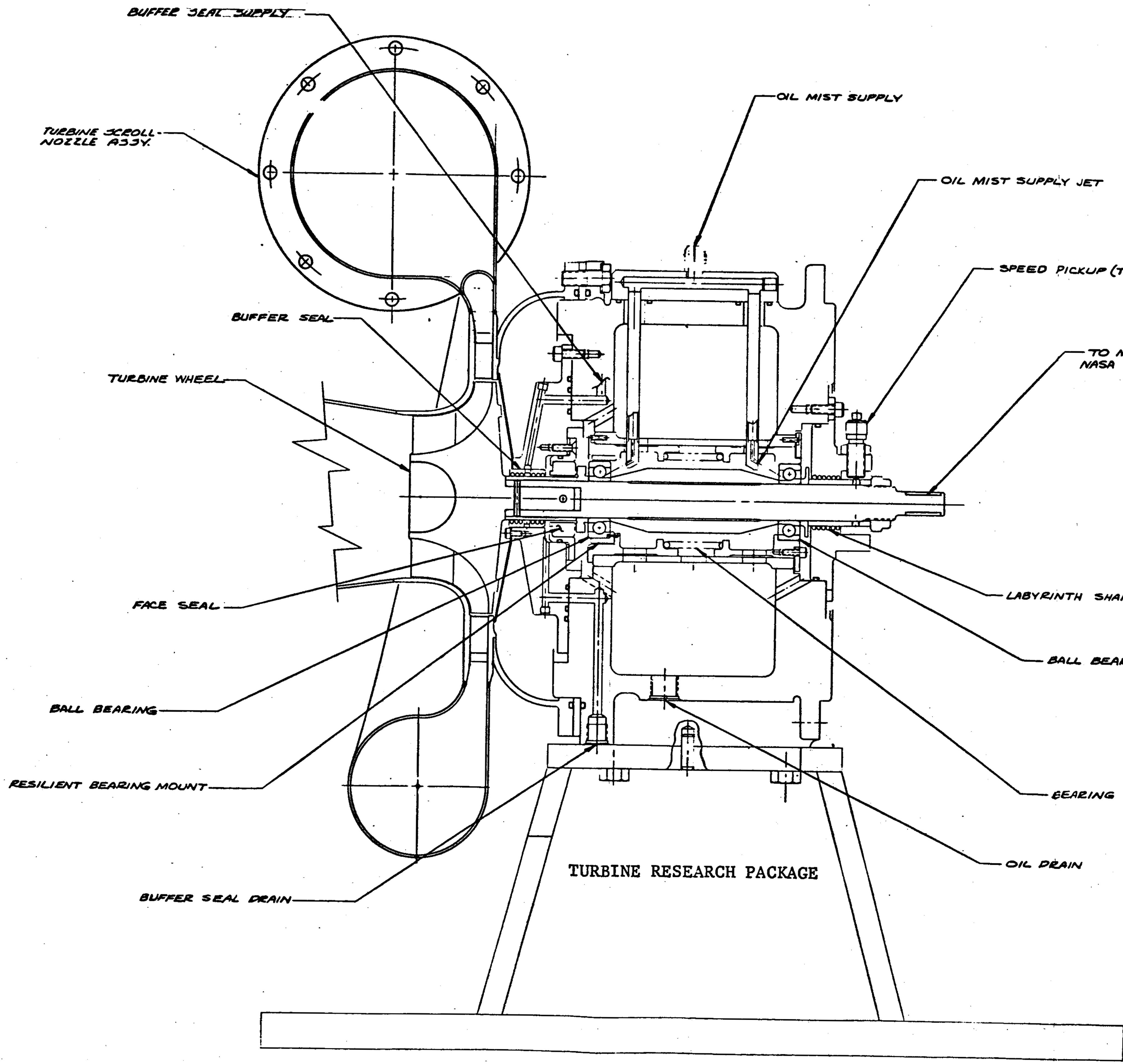

BUFFER SEAL SUPPLY
TURBINE SCROLL-NOZZLE ASSY.
OIL MIST SUPPLY
OIL MIST SUPPLY JET
SPEED PICKUP (TYP)
TO MATE WITH COUPLING NASA DRAWING NO. CC844330
BUFFER SEAL
TURBINE WHEEL
FACE SEAL
BALL BEARING
RESILIENT BEARING MOUNT
BUFFER SEAL DRAIN
LABYRINTH SHAFT SEAL
BALL BEARING
BEARING PRELOAD, SPRING
OIL DRAIN
TURBINE RESEARCH PACKAGE

FIGURE 15

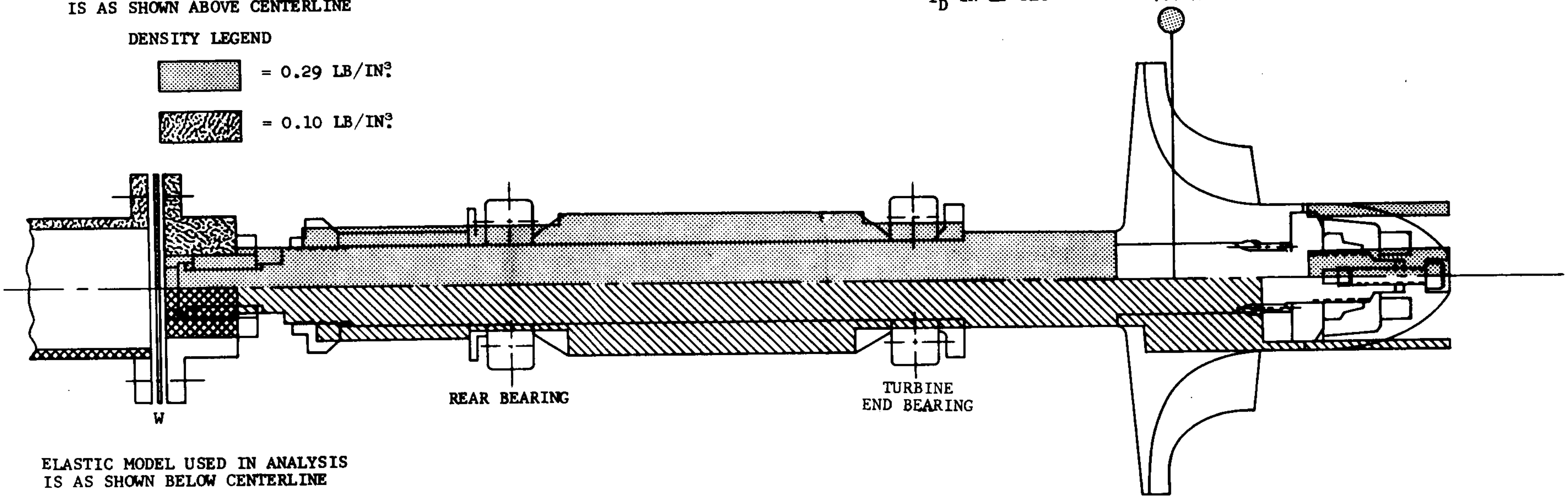
	TURBINE WHEEL
MASS LB SEC^2/IN.	0.0094
I_p IN-LB-SEC^2	0.0156
I_D IN-LB-SEC^2	0.0098

MASS MODEL USED IN ANALYSIS
IS AS SHOWN ABOVE CENTERLINE

DENSITY LEGEND

= 0.29 LB/IN^3.

= 0.10 LB/IN^3.



ELASTIC MODEL USED IN ANALYSIS
IS AS SHOWN BELOW CENTERLINE

LEGEND OF MODULUS
OF ELASTICITIES

E = $2.9(10)^7$ LB/IN^2.

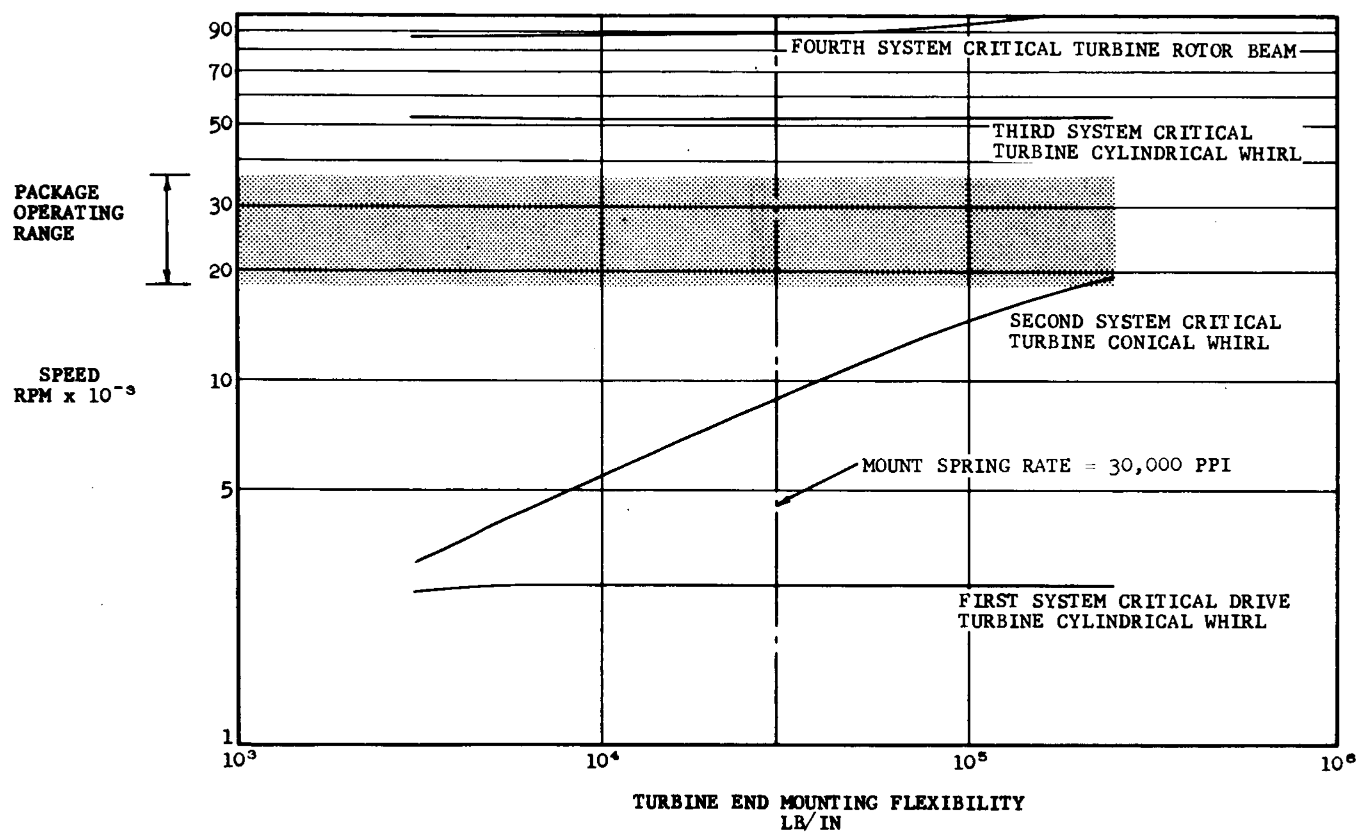
E = $1.0(10)^7$ LB/IN^2.

NOTES: (1) DRIVE TURBINE MOUNTED ON FLEXIBLE MOUNTS WITH 1,500 LB PER INCH SPRING RATES.

(2) THE MOMENT TRANSMITTED THROUGH THE 'WAFERS' WAS ASSUMED NEGLIGIBLE. IN ESSENCE, A PINNED JOINT WAS ASSUMED AT EACH END OF THE FLEXIBLE COUPLING.

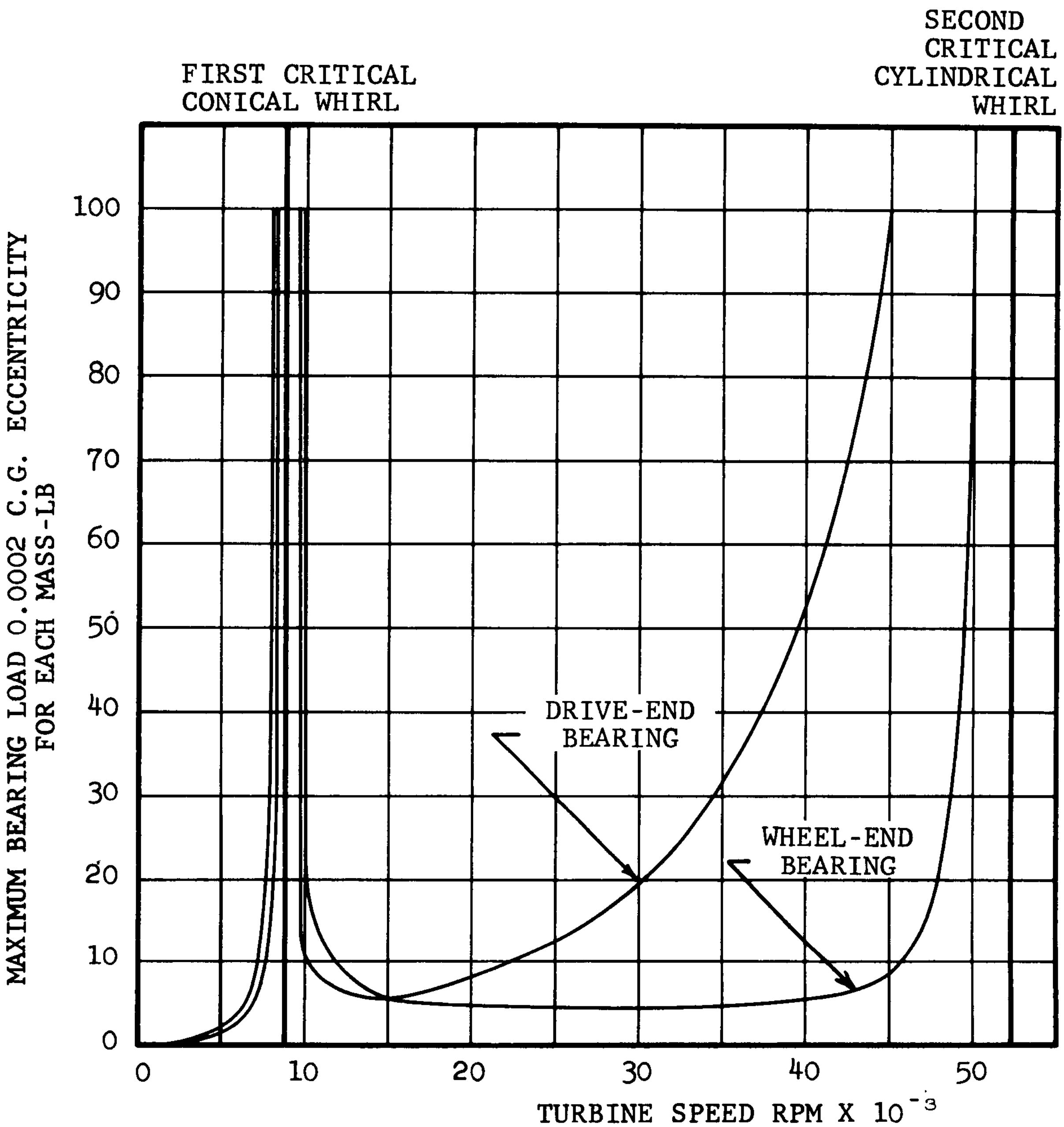
FIGURE 16

SYSTEM USED IN CRITICAL SPEED
AND BEARING LOAD ANALYSIS OF
THE BRU TURBINE RESEARCH
PACKAGE



NOTES: (1) REF. FIGURE 16
(2) REAR BEARING SPRING RATE = $2.5(10)^5$ LB/IN.

FIGURE 17
BRU TURBINE RESEARCH PACKAGE CRITICAL SPEEDS AS A FUNCTION OF TURBINE END MOUNTING FLEXIBILITY WITH REAR BEARING RIGIDLY MOUNTED



NOTES:
1. REF. FIGURE 17
2. REAR BEARING RIGIDLY MOUNTED
$K = 2.5\ (10)^5$ LB PER INCH
3. TURBINE END BEARING FLEX MOUNTED
$K = 3\ (10)^4$ LB PER INCH

FIGURE 18

BEARING LOADS FOR BRU
TURBINE RESEARCH PACKAGE

3.5 Bearing and Seal Design Data and Drawings

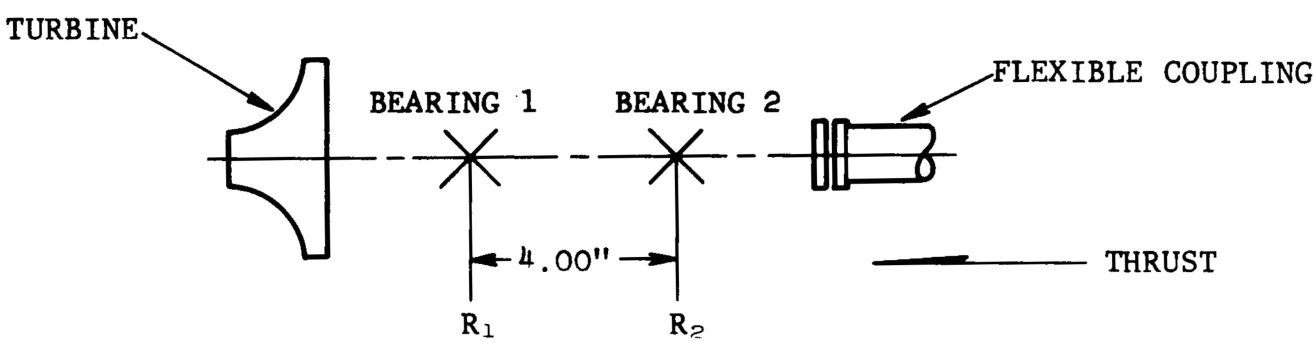
The angular-contact rolling-element bearing selected as a result of digital computer techniques for the turbine research package should adequately meet the design objective of a time between overhaul (TBO) of 300 hours minimum when using air-oil mist lubrication (MIL-L-7808). The major characteristics of the chosen bearing (Part 358500) are:

Bore diameter	20 mm
Outside diameter	42 mm
Width	12 mm
Number of balls	11
Ball diameter	9/32 inch
Inner-race curvature	52 to 53 percent of ball diameter
Outer-race curvature	52 to 53 percent of ball diameter
Contact angle	16 degrees
Ring and ball material	Consumable-electrode vacuum-melted M-50 tool steel
Separator material	Iron-silicon-bronze, silver-plated

The unidirection (1 "g") radial bearing loads and thrust loads assumed for the analysis are shown in Table 2. The predicted bearing system life, B_1, for preloads of 10,30, and 60 pounds for the turbine research package is shown in Figure 19. The predicted power loss per bearing for preloads of 10, 30, and 60 pounds is plotted in Figure 20. Representative package speeds, bearing loads,

TABLE 2

UNIDIRECTIONAL BEARING LOADS ASSUMED FOR
BEARING ANALYSES, TURBINE RESEARCH PACKAGE



Note: Bearing 2 takes thrust loads in the direction shown.

	R_1(lbs)	R_2(lbs)	Thrust (lbs)
Turbine Package	7.5	-0.5	31.0

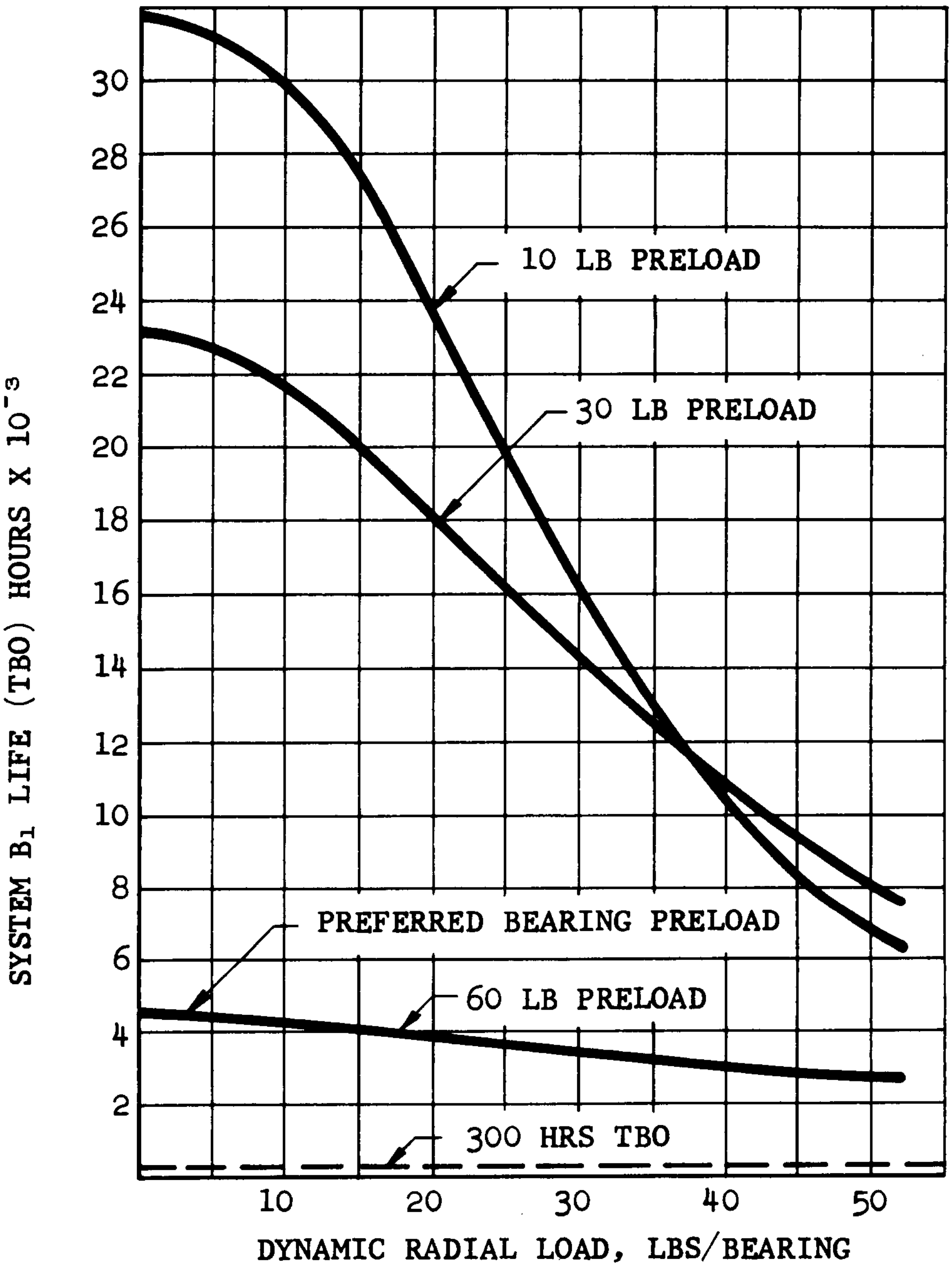
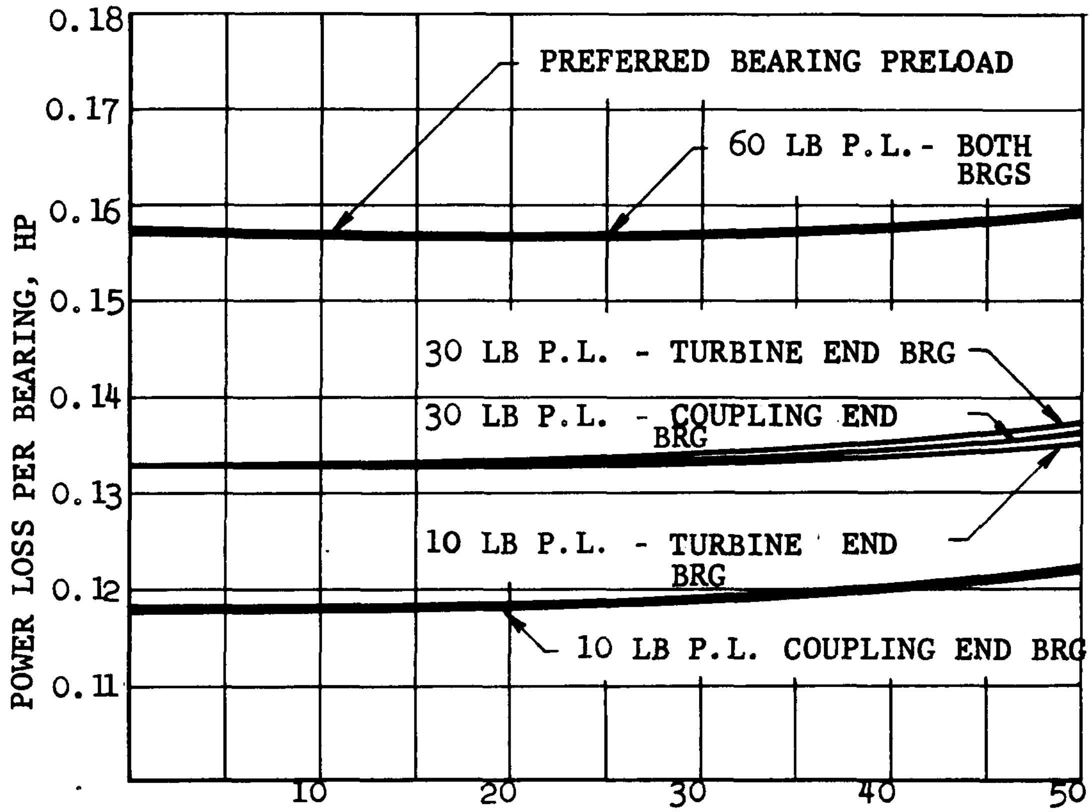


FIGURE 19

BEARING SYSTEM LIFE, B_1, FOR NASA BRU
TURBINE RESEARCH PACKAGE BEARING P/N 358500



DYNAMIC RADIAL LOAD, LBS.

FIGURE 20

BEARING POWER LOSS FOR NASA BRU
TURBINE RESEARCH PACKAGE
BEARING P/N 358500

and predicted system B_1 life is presented in Table 3. It is evident that the TBO design objective (300 hours minimum) for the research package can be easily met. The bearing configuration and material requirements are shown in AiResearch Source Control Drawing 358500.

The carbon-face contact seal for the turbine research package is shown on Drawing 699683. Five vendors indicated their desire to participate in this program, three of whom were approved by the Contractor. The seal designs proposed by each of the three vendors were quite similar (standard O-ring configuration with wave washer spring loading). The design is inherently insensitive to sealing pressure differentials and direction of pressure differentials. The only face pressure incurred will result from the spring loading and O-ring drag. Thus, a very wide range of turbine-wheel back-face pressures can be readily accommodated without seal carbon-face leakage or destruction.

3.6 Turbine Instrumentation

The turbine research package has a full complement of static pressure instrumentation and provisions for the addition, by the NASA, of total pressure and temperature instrumentation to assist in the aerodynamic performance evaluation of the turbine. The following is a list of the instrumentation and the provisions therefor, as installed on the turbine research package:

(a) Four static pressure taps, 90° apart, one-half duct diameter downstream of the scroll inlet flange.

(b) Two total pressure-total temperature taps, 90° apart, one-half inch downstream of the static pressure taps.

(c) Five static pressure taps at four cross-channel positions across the nozzle exit.

TABLE 3

TURBINE RESEARCH PACKAGE
BEARING SYSTEM B_1 LIFE (TBO)

Turbine (60 pounds bearing preload):

Speed (rpm)	Max. Bearing Load (lbs)	B_1 Life (hours)
18,250	7	4,400
30,400	20	3,900
36,500	36	3,100

(d) Three C.A. thermocouples located on the outer face of each ball bearing.

(e) Two sets of three each machined bosses, equally spaced, placed over the turbine wheel for probes to measure blade clearance.

(f) Five Electro Products (No. 3016) shaft speed pickups are provided and installed, two of which are 90° apart.

In addition, plugs have been provided to seal the holes in the unit when the research package is to be run without instrumentation.

The following auxiliary equipment and spares were supplied to the NASA in support of the turbine research package:

(a) One set of spare stub-end flanges to connect the turbine inlet and exit to laboratory piping.

(b) The balanced coupling (NASA Drawing CC 844330).

(c) Three sets of spares of all bearings, seals, packings, lockwashers, and other expendable items.

4. GENERAL UNIT DESCRIPTION

The dimensional outline of the turbine research package is shown in Drawing 699800. This drawing also defines the interfaces between (a) the end of the turbine shaft machined to mate with the drive coupling, Drawing 699667 (NASA Drawing CC844330), (b) the bolt flanges at the compressor inlet and discharge to permit attachment to adaptor flanges, Drawings 699769 and 699770 and (c) the mating electrical connectors (temperature and speed) and pipe fittings. General operating conditions for the unit are also specified.

A cross-sectional view of the turbine research package is shown in Assembly Drawing 699801. The unit consists of the wheel assembly (Item 8) mounted in the main housing (Item 1) on two antifriction bearings (Item 6, also Drawing 358500). The wheel-end bearing is resiliently mounted with a spring rate of 30,000 pounds per inch using the bearing mount assembly (Item 5). This spring rate was chosen so that the operating speed range would be between a low second critical and a very high third critical; a coil spring (Item 26) provides 60 pounds of axial preload on the bearings. An oil jet (Item 23) supplies pressurized, air-oil mist to each bearing.

Labyrinth type seals are provided at each end of the housing. The wheel end seal has a purge chamber located in the middle of the seal. The wheel end is also equipped with a carbon-face type oil seal (Item 9, also Drawing 699683).

The turbine scroll (Item 22) is attached to the main housing by a bolted flange. Shimming to obtain the desired turbine-wheel-shroud-face clearance is accomplished at this flange by providing a shim of predetermined thickness between the housing and the scroll flange. A design value of the clearance was established at 0.009-0.011 inch. Sealing at this shim is accomplished with the O-rings (NAS 1593-174). A rigid mounting base (Item 2) provides for mounting the turbine research package on a test stand bed-plate.

5. TURBINE RESEARCH PACKAGE ACCEPTANCE TESTING

The turbine research package acceptance test was performed at the AiResearch Manufacturing Company, Phoenix, Arizona, on October 25, 1967. All testing was conducted at the Phoenix Division's laboratory facility, Building "N", and was witnessed by a NASA representative from the NASA-Lewis Research Laboratory.

The acceptance test rig consisted of the turbine research package mounted on a laboratory test stand and supplied with plant compressed air through a flexible duct. The air-oil mist lubrication was supplied to the unit by a specially calibrated Norgren oiler.

The acceptance test was conducted as follows: A critical speed survey of the unit was made while slowly increasing the speed of the system to 30,400 rpm (100-percent design speed). The system was stabilized at this speed for the required 30 minutes, during which time the unit's speed, vibration, and bearing temperature were manually recorded at five-minute intervals. Following this 30-minute cycle, the speed of the unit was increased to 36,480 rpm (120-percent design speed) for 10 minutes. Data recording was continued at 5-minute intervals. The system was then shut down and the acceptance test was considered to be satisfactorily completed. Figures 21 and 22 show the unit on the test stand after the acceptance test.

Acceptance test data, including assembly instructions, parts list, delivery spares and the unit build history have been delivered to the NASA Lewis Research Center in a separate document in accordance with contract requirements.

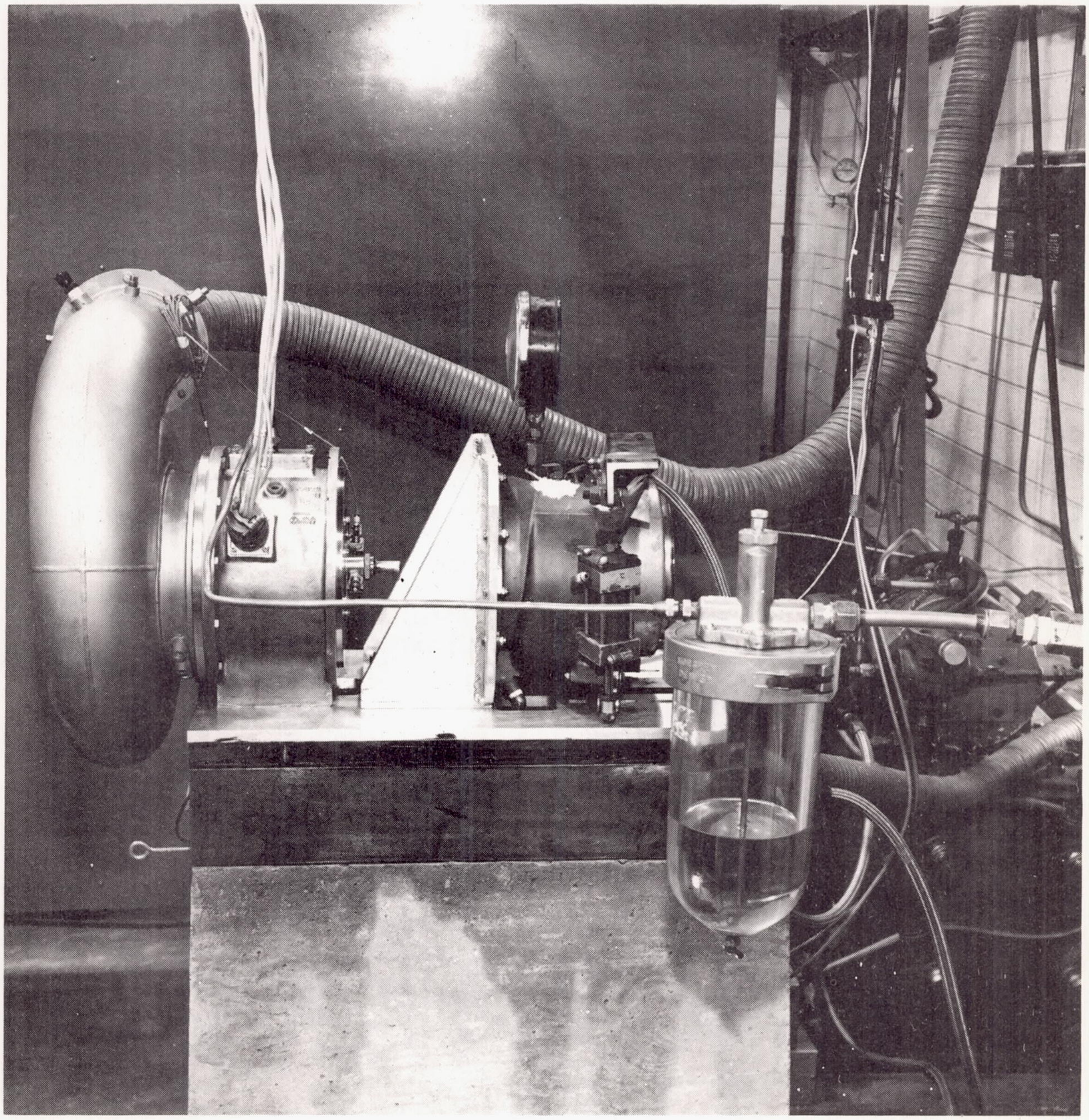


FIGURE 21

RIGHT SIDE VIEW OF
TURBINE RESEARCH PACKAGE ON TEST STAND

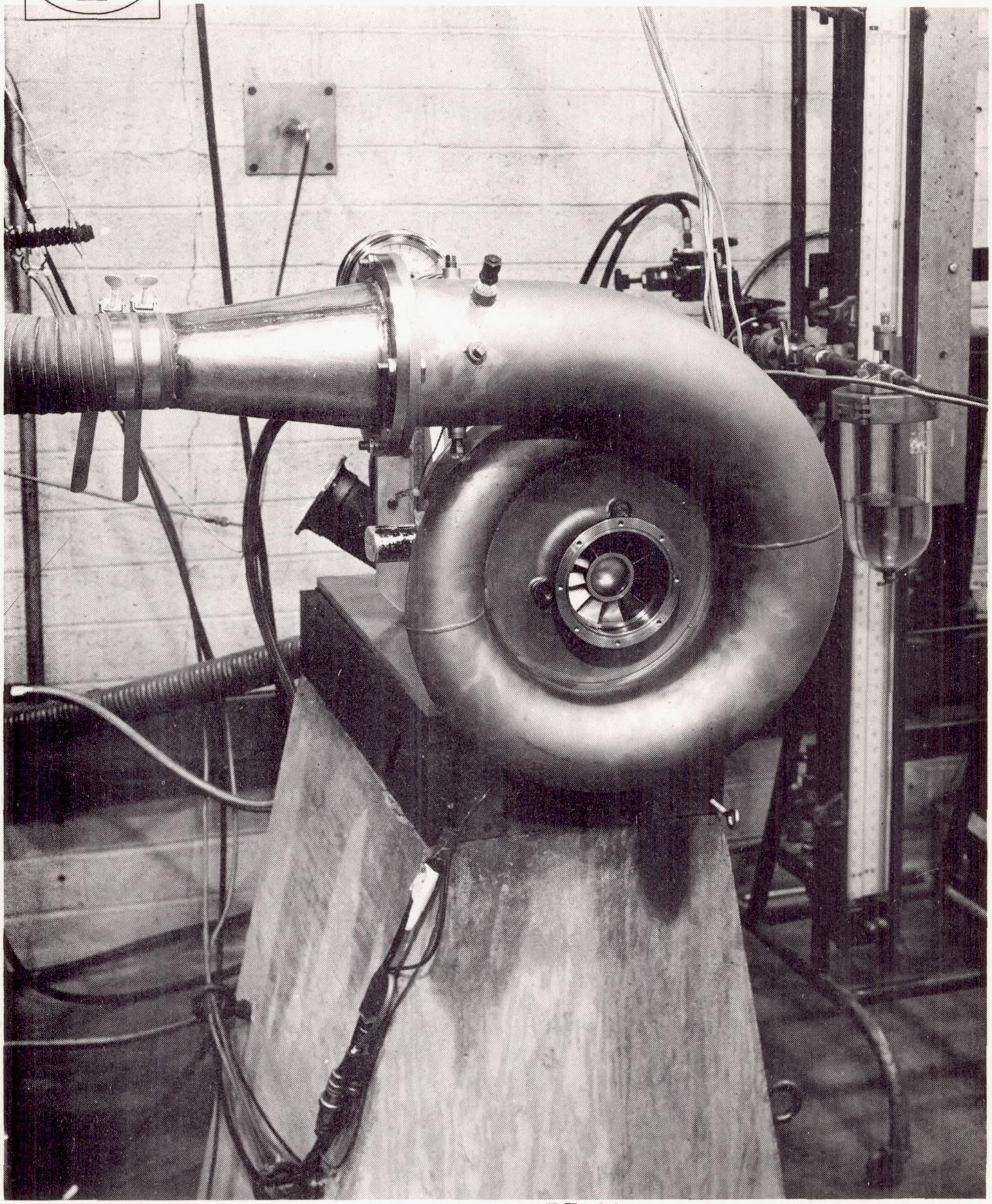


FIGURE 22

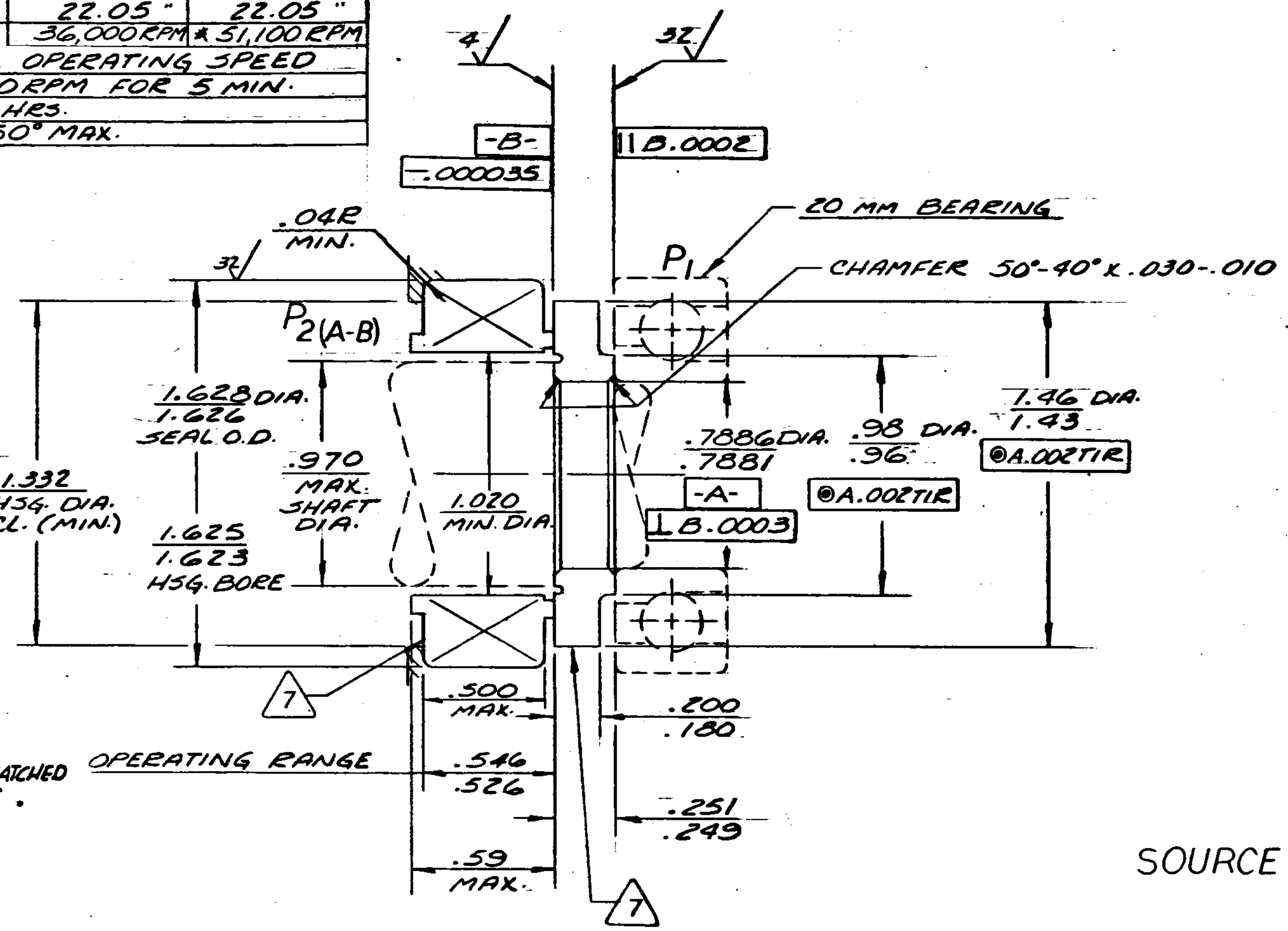
LEFT FRONT VIEW OF
TURBINE RESEARCH PACKAGE ON TEST STAND

MP-18092

PART NO.
699683-1

OPERATING CONDITIONS			
	P_1	P_{2-A}	P_{2-B}
MEDIUM	AIR-OIL MIST (MIL-L-7808)	HELIUM-XENON	ARGON
	14.7 PSIA 14.7 " 14.7 "	6.5 PSIA 11.5 " 22.05 "	6.5 PSIA 11.5 " 22.05 "
SPEED		36,000 RPM	* 51,100 RPM
* NOTE: NORMAL OPERATING SPEED			
OVERSPEED — 61,320 RPM FOR 5 MIN.			
LIFE 300 HRS.			
TEMPERATURE 250° MAX.			

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



11. THESE PARTS TO BE MANUFACTURED, INSPECTED, STOCKED AND SOLD AS REPLACEMENT PARTS IN MATCHED SETS ONLY.
10. SHAFT MATERIAL: 4340
9. SEAL HOUSING MATERIAL: 300 SERIES STAINLESS
8. PROCUREMENT SOURCE(S) PER ASL 699683.
7. AIRESEARCH PART NUMBER & SERIAL NUMBER OF MATCHED SET HERE PER AIRESEARCH SPEC. 5014, CLASS II.
6. ALL DESIGN AND PART NUMBER CHANGES REQUIRE PRIOR AIRESEARCH APPROVAL.
5. ONLY THE ITEM DESCRIBED ON THIS DRAWING WHEN PROCURED FROM THE VENDOR(S) LISTED HEREON IS APPROVED BY AIRESEARCH MANUFACTURING COMPANY, PHOENIX, ARIZONA FOR USE IN THE APPLICATION(S) SPECIFIED HEREON. A SUBSTITUTE ITEM SHALL NOT BE USED WITHOUT PRIOR TESTING AND APPROVAL BY AIRESEARCH MANUFACTURING COMPANY OR BY THE GOVERNMENT PROCURING ACTIVITY.
4. DRAWING REVISIONS FOR SUBSTITUTE ITEMS SHALL NOT BE MADE WITHOUT PRIOR APPROVAL BY AIRESEARCH MANUFACTURING COMPANY.
3. IDENTIFY PACKAGING WITH AIRESEARCH PART NUMBER.
2. PARTS PROCURED BY VENDOR PART NUMBER SHALL BE PROCURED IN ACCORDANCE WITH THIS AIRESEARCH SOURCE CONTROL DRAWING.
1. DETAILS OF DESIGN AND CONSTRUCTION OTHER THAN SHOWN SHALL BE AT OPTION OF VENDOR.

SOURCE CONTROL DRAWING

See tab block (upper left corner) for PART NUMBER

QUANTITY REQD	ITEM NO.	PART NO.	SYM	DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	ZONE
	←ASSY						

LIST OF MATERIAL

CRITICAL ITEM

SATISFACTORY PERFORMANCE OF THE END PRODUCT DEPENDS ON THE INTEGRITY AND RELIABILITY OF THIS SELECTED CRITICAL ITEM. THE GARRETT CORPORATION RECOMMENDS PROCUREMENT FROM THE ORIGINAL SUPPLIER AS SET FORTH IN ASPR 1-313.

UNLESS OTHERWISE SPECIFIED ON THIS DRAWING, FABRICATION OF THIS ITEM SHALL BE IN ACCORDANCE WITH AIRESEARCH SPECIFICATION SC-5535, STANDARD DRAWING INTERPRETATIONS.

REQD	NEXT ASSY	USED ON
1(-1)	699671-1	699670-1
HEAT TREATMENT		PROCESS
HARDNESS AND SPEC		NAME AND SPEC

SIGNATURES	DATES
DFT	12-6-66
CHK	1-11-67
MFG	
MATL	
STRESS	
AERO	
APPD	1-13-67
APPD	1-13-67
DESIGN ACTIVITY APPD	1-16-67
OTHER ACTIVITY APPD	

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DWG TITLE: SEAL & ROTOR SET, MATCHED

SIZE	CODE IDENT NO.	DWG NO.
C	99193	699683
SCALE 2X	WT -	SHEET 1 OF 1

FORM P3548A
DIETZGEN 138W-3 — 8IMB

OUTLINE NUMBER	END UNIT IDENTIFICATION №	ASSEMBLY NUMBER
699800-1	NOC 699800-1-1	699801-1

SEE TAB BLOCK (UPPER LEFT CORNER) FOR OUTLINE & IDENTIFICATION NUMBER

4. OPERATING CONDITIONS:
LUBRICATING FLUID : MIL-O-7808
AIR-OIL MIST RATIO : 200 TO 1 (BY WEIGHT)
AIR FLOW (AIR-OIL MIST) : 0.5 LB/MIN
TEST OPERATING SPEED RANGE : 18,750 TO 36,500 RPM

3. MAY BE PURCHASED FROM:
CONSOLIDATED ELECTRO DYNAMICS CORP.
PASADENA, CALIFORNIA

2. POSITIONAL AND GEOMETRIC TOLERANCE SYMBOLS PER MIL-STD-8.

1. ALL DIMENSIONS SHOWN ARE FOR INSTALLATION AND ASSEMBLY PURPOSES ONLY

DWG NO. 699800 SHEET 1/1

QUANTITY REQD	ITEM NO.	PART NO.	SYM	DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	UNIT WT	ZONE
		←ASSY		LIST OF MATERIAL				

~~UNLESS OTHERWISE SPECIFIED ON THIS DRAWING FABRICATION OF THIS ITEM SHALL BE IN ACCORDANCE WITH AIRESEARCH SPECIFICATION SE-535, STANDARD DRAWING IN-TERPRETATIONS~~

REQD | NEXT ASSY | USED ON | FINAL
HEAT TREATMENT | PROCESS

SIGNATURES	DATES
DFT	5-10-67
CHK	5-17-67
	5-18-67
APPD	5/18/67
APPD	7-20-67
APPD	7-26-67
DESIGN ACTIVITY APPD	7-27-67

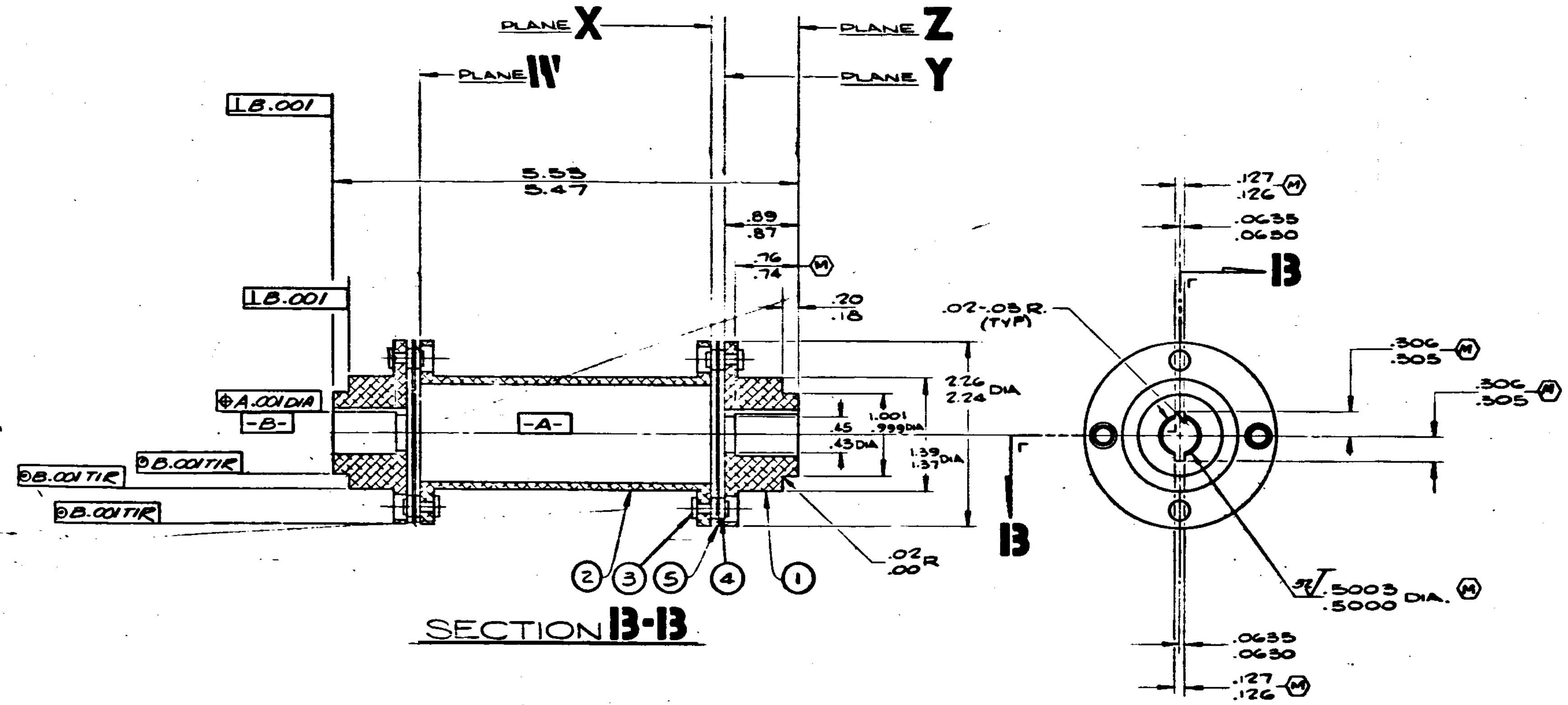
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DWG TITLE: RESEARCH PACKAGE OUTLINE, TURBINE

SIZE J | CODE IDENT NO. 99193 | DWG NO. 699800

SCALE 1/1 & NOTED | WT | SHEET 1 OF 1

PART N°
699667-1



13. POSIONAL AND GEOMETRIC TOLERANCE SYMBOLS PER MIL-STD-8 .

12. (C) DESIGNATES CRITICAL CHARACTERISTIC
(M) DESIGNATES MAJOR CHARACTERISTIC

(M) 11. DYNAMIC BALANCE REQUIREMENTS:

11.1 BALANCING SPEED 2500 RPM MIN.

11.2 A SINGLE ARBOR PRE-BALANCED TO WITHIN .0002 OZ-IN. AND HAVING DATUM "B" LOCATING DIAS CONCENTRIC TO ITS ROTATING AXIS WITHIN .0001 TIR SHALL BE UTILIZED THROUGHOUT BALANCING PROCEDURE.

11.3 DYNAMICALLY BALANCE ITEMS INDIVIDUALLY IN PLANES Z & Y TO WITHIN .0002 OZ-IN. REMOVE METAL FROM PLANES Z & Y IF NECESSARY.

11.4 COMPLETELY ASSEMBLY COUPLING & DYNAMICALLY BALANCE ASSEMBLY ABOUT PLANES W & X TO WITHIN .0004 OZ-IN. REMOVE METAL FROM PLANES W & X IF NECESSARY.

10. NO SET SCREWS, ACCESS HOLES OR ANODIZE.
9. FINISH ALL OVER EXCEPT NOTED √.
8. DETAILS OF DESIGN AND CONSTRUCTION OTHER THAN SHOWN TO BE AT OPTION OF VENDOR.
7. PARTS PROCURED BY VENDOR PART NUMBER SHALL BE PROCURED IN ACCORDANCE WITH THIS AIRESEARCH SOURCE CONTROL DRAWING.
6. IDENTIFY PACKAGING WITH AIRESEARCH PART NUMBER.
5. DRAWING REVISIONS FOR SUBSTITUTE ITEMS SHALL NOT BE MADE WITHOUT PRIOR AIRESEARCH APPROVAL.
4. ONLY THE ITEM DESCRIBED ON THIS DRAWING WHEN PROCURED FROM THE VENDORS LISTED HEREON IS APPROVED BY AIRESEARCH MANUFACTURING CO OF PHOENIX, ARIZONA FOR USE IN THE APPLICATIONS SPECIFIED HEREON. A SUBSTITUTE ITEM SHALL NOT BE USED WITHOUT PRIOR TESTING AND APPROVAL BY AIRESEARCH MFG. CO OR BY THE GOVERNMENT PROCURING ACTIVITY.
3. ALL DESIGN AND PART NUMBER CHANGES REQUIRE PRIOR AIRESEARCH APPROVAL.
2. APPLY AIRESEARCH PART NUMBER PER AIRESEARCH SPEC MC5014 CL V A.
1. PROCUREMENT SOURCES PER ASL 699667.

NOTES:

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

SEE TAB. BLOCK (UPPER LEFT CORNER) FOR PART NUMBER.

SOURCE CONTROL DRAWING

QUANTITY REQD		ITEM NO.	PART NO.	SYM	DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	ZONE
2		5	-19		DISC		BERYLLIUM COPPER QQ-C-533	
16		4	-17		WASHER		BRASS QQ-B-626	
8		3	-15		RIVET		BRASS QQ-B-626	
1		2	-13		CENTER MEMBER		AL ALLOY AMS 4122/7075-T6	
2		1	699667-11		FLANGE		AL ALLOY AMS 4122/7075-T6	
	←ASSY				LIST OF MATERIAL			

REQD	NEXT ASSY	USED ON
(-1)	699681-1	699680-1
(-1)	699801-1	699800-1
(-1)	699651-1	699650-1

HEAT TREATMENT	PROCESS
HARDNESS AND SPEC	NAME AND SPEC

SIGNATURES	DATES
DFT S.J. SHMAN	3-21-67
CHK	5-1-67
MFG	5-1-67
MATL	5-4-67
STRESS	5-1-67
AERO	
APPD	5-1-67
APPD	5-8-67
DESIGN ACTIVITY APPD	5-8-67
OTHER ACTIVITY APPD	

UNLESS OTHERWISE SPECIFIED ON THIS DRAWING, FABRICATION OF THIS ITEM SHALL BE IN ACCORDANCE WITH AIRESEARCH SPECIFICATION SC-5535, STANDARD DRAWING INTERPRETATIONS.

CRITICAL ITEM
SATISFACTORY PERFORMANCE OF THE END PRODUCT DEPENDS ON THE INTEGRITY AND RELIABILITY OF THIS SELECTED CRITICAL ITEM. THE GARRETT CORPORATION RECOMMENDS PROCUREMENT FROM THE ORIGINAL SUPPLIER AS SET FORTH IN ASPR 1-313

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

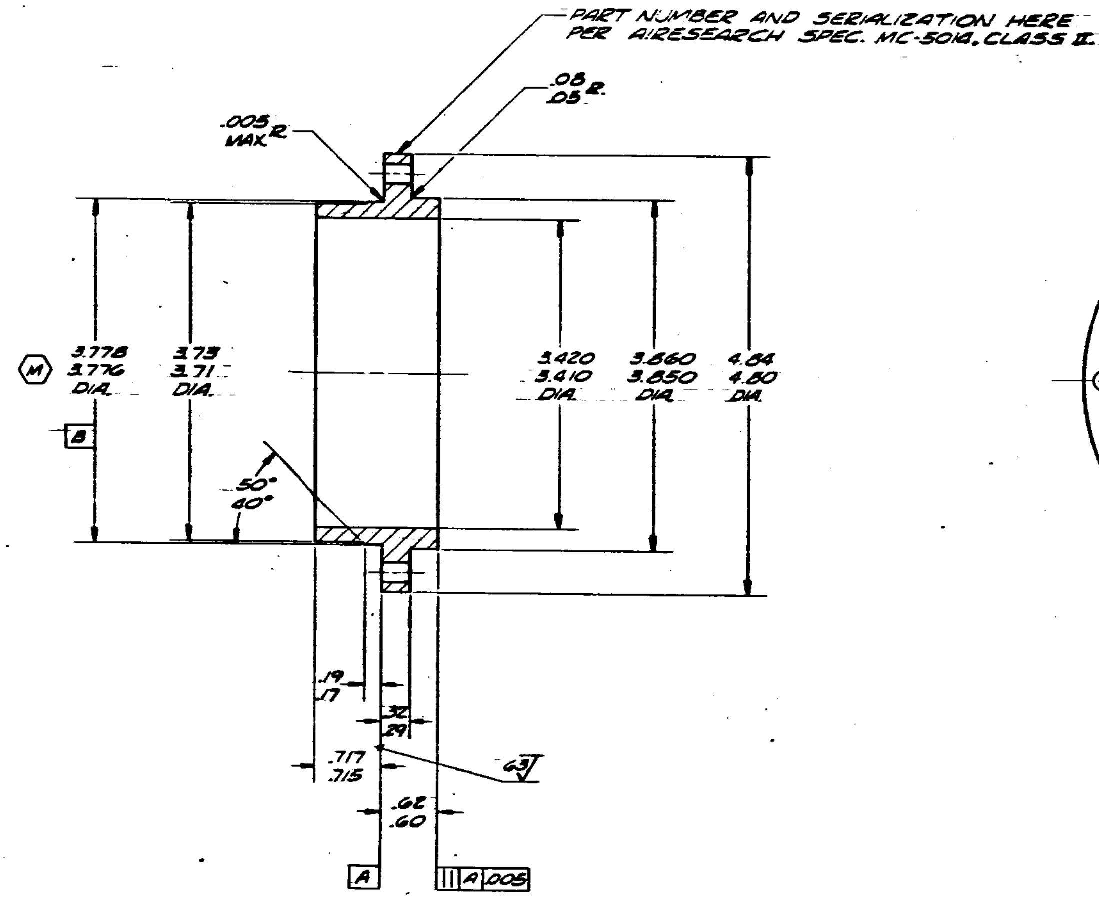
DWG TITLE
COUPLING ASSEMBLY, DRIVE

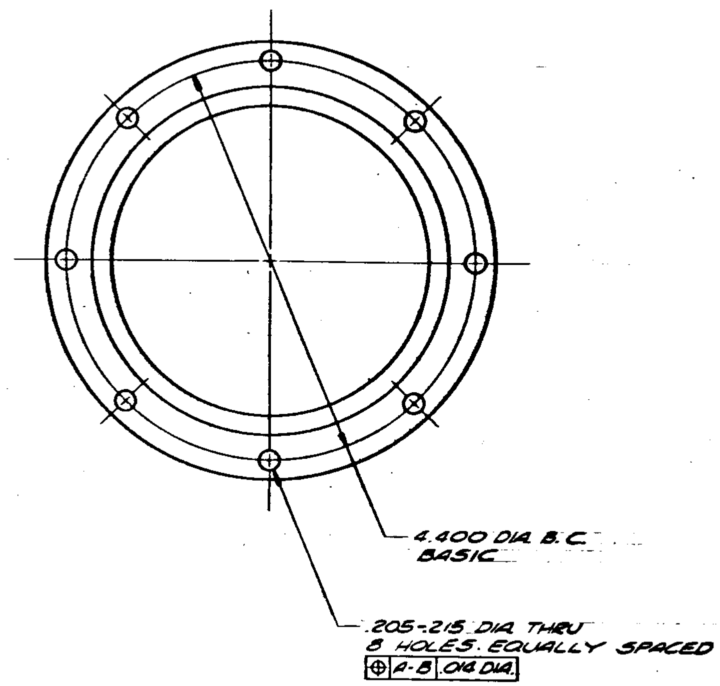
SIZE	CODE IDENT NO.	DWG NO.
D	99193	699667
SCALE 1/1	WT -	SHEET 1 OF 1

699667

PART NUMBER
699769-1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED





4. FLUORESENT PENETRANT INSPECT PER AMS 2645.

3. (M) Designate Major Characteristics

2. SERIAL NUMBER CONTROL MUST BE MAINTAINED ON THIS PART THROUGHOUT MANUFACTURING AND ASSEMBLY CYCLES AND AFTER FINISH MACHINING. SERIAL NUMBERS SHALL BE APPLIED BY THE METHOD AND AT THE LOCATION SPECIFIED.

1. FINISH ALL OVER 125 OR AS NOTED.

SEE TAB. BLOCK (UPPER LEFT CORNER) FOR PART NUMBER.

CRITICAL ITEM

SATISFACTORY PERFORMANCE OF THE END PRODUCT DEPENDS ON THE INTEGRITY AND RELIABILITY OF THIS SELECTED CRITICAL ITEM. THE GARRETT CORPORATION RECOMMENDS PROCUREMENT FROM THE ORIGINAL SUPPLIER AS SET FORTH IN ARPI 1-313.

UNLESS OTHERWISE SPECIFIED ON THIS DRAWING, FABRICATION OF THIS ITEM SHALL BE IN ACCORDANCE WITH AIRESEARCH SPECIFICATION SC-5535, STANDARD DRAWING INTERPRETATIONS.

QUANTITY REQD	ITEM NO.	PART NO.	SYM	DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	ZONE
						347 CRES AMS 5646 or 5512	
←ASSY				LIST OF MATERIAL			

REQD	NEXT ASSY	USED ON
1(-1)	FINAL	699769-1
HEAT TREATMENT		PROCESS
HARDNESS AND SPEC		NAME AND SPEC: NOTED

SIGNATURES		DATES
DFT	[illegible]	4-10-67
CHK	[illegible]	4-14-67
ENGR	[illegible]	4-14-67
MATL	[illegible]	4-16-67
STRESS	A. [illegible]	4-14-67
AERO		
APPD	A J Wroclawski	4-17-67
APPD	[illegible]	4-14-67
DESIGN ACTIVITY APPD	[illegible]	4-17-67
OTHER ACTIVITY APPD		

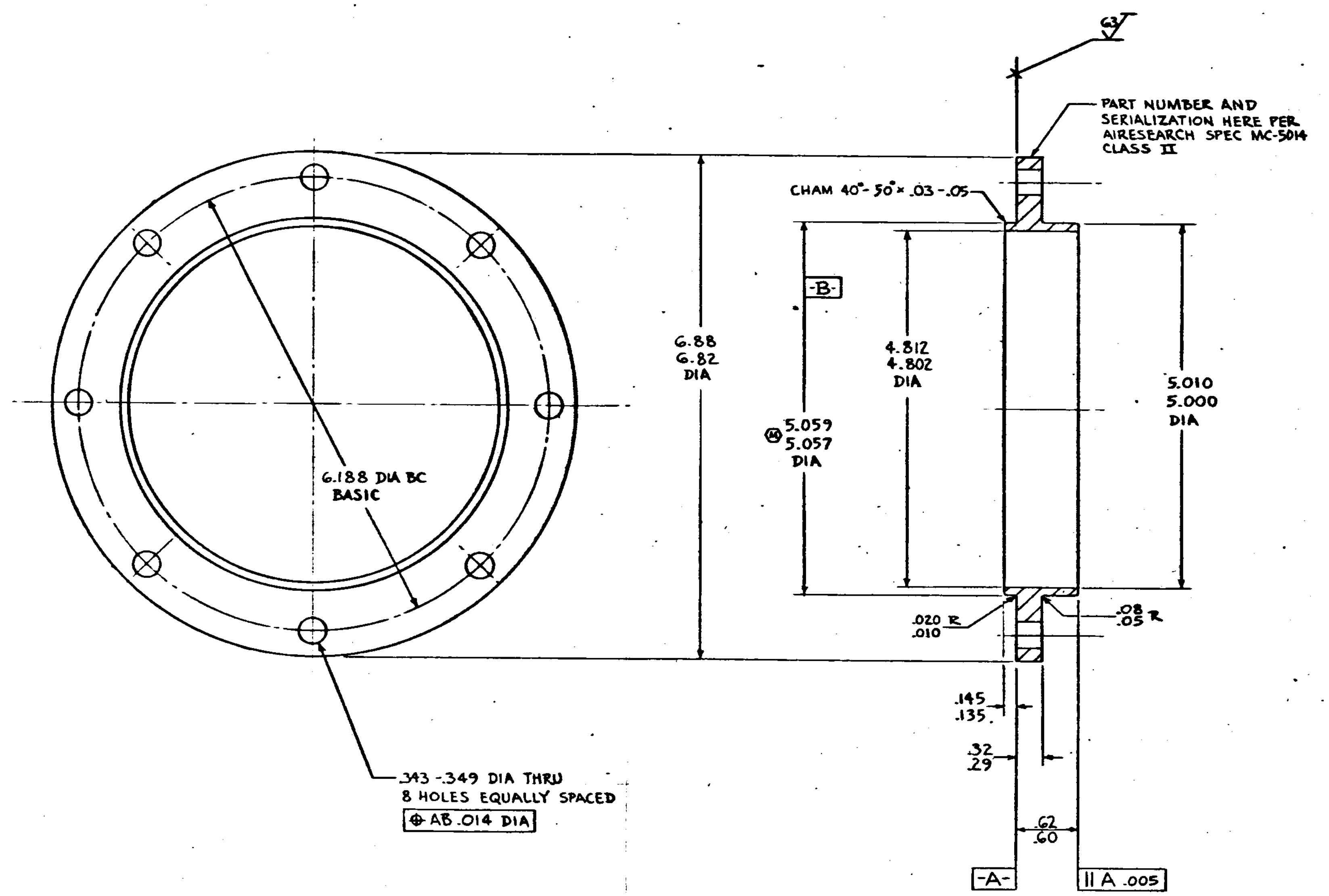
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DWG TITLE: FLANGE, TURBINE OUTLET

SIZE	CODE IDENT NO.	DWG NO.
D	99193	699769
SCALE 1/1	WT	SHEET 1 OF 1

PART NUMBER
699770-1

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED



SEE TAB. BLOCK (UPPER LEFT CORNER) FOR PART NUMBER.

4. FLUORESCENT PENETRATE INSPECT PER AMS 2645
3. Ⓜ Designate Major Characteristics
2. SERIAL NUMBER CONTROL MUST BE MAINTAINED ON THIS PART THROUGHOUT MANUFACTURING AND ASSEMBLY CYCLES AND AFTER FINISH MACHINING. SERIAL NUMBERS SHALL BE APPLIED BY THE METHOD AND AT THE LOCATION SPECIFIED.
1. FINISH ALL OVER 125√ EXCEPT AS NOTED

CRITICAL ITEM
SATISFACTORY PERFORMANCE OF THE END PRODUCT DEPENDS ON THE INTEGRITY AND RELIABILITY OF THIS SELECTED CRITICAL ITEM. THE GARRETT CORPORATION RECOMMENDS PROCUREMENT FROM THE ORIGINAL SUPPLIER AS SET FORTH IN ASPR 1-313.

UNLESS OTHERWISE SPECIFIED ON THIS DRAWING, FABRICATION OF THIS ITEM SHALL BE IN ACCORDANCE WITH AIRESEARCH SPECIFICATION SC-5535, STANDARD DRAWING INTERPRETATIONS.

QUANTITY REQD	ITEM NO.	PART NO.	SYM	DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	ZONE
						347 CRES AMS 5646 OR 5512	
		←ASSY					

LIST OF MATERIAL

REQD	NEXT ASSY	USED ON
1 (-1)	FINAL	699770-1

HEAT TREATMENT	PROCESS
HARDNESS AND SPEC	NAME AND SPEC
	NOTED

SIGNATURES		DATES
DFT	F. J. Brown	4-13-67
CHK		4-14-67
ENGR	R. E. Johnson	4-14-67
MATL		4-14-67
STRESS		4-19-67
AERO		
APPD	A. J. Wesolowski	4-17-67
APPD		4-14-67
DESIGN ACTIVITY APPD		4-17-67
OTHER ACTIVITY APPD		

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

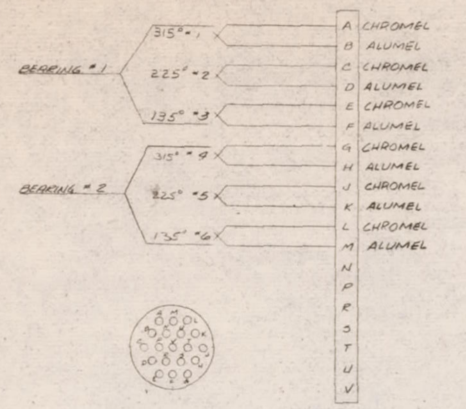
DWG TITLE: FLANGE, TURBINE INLET

SIZE	CODE IDENT NO.	DWG NO.
D	99193	699770

SCALE 1/1	WT —	SHEET 1 OF 1

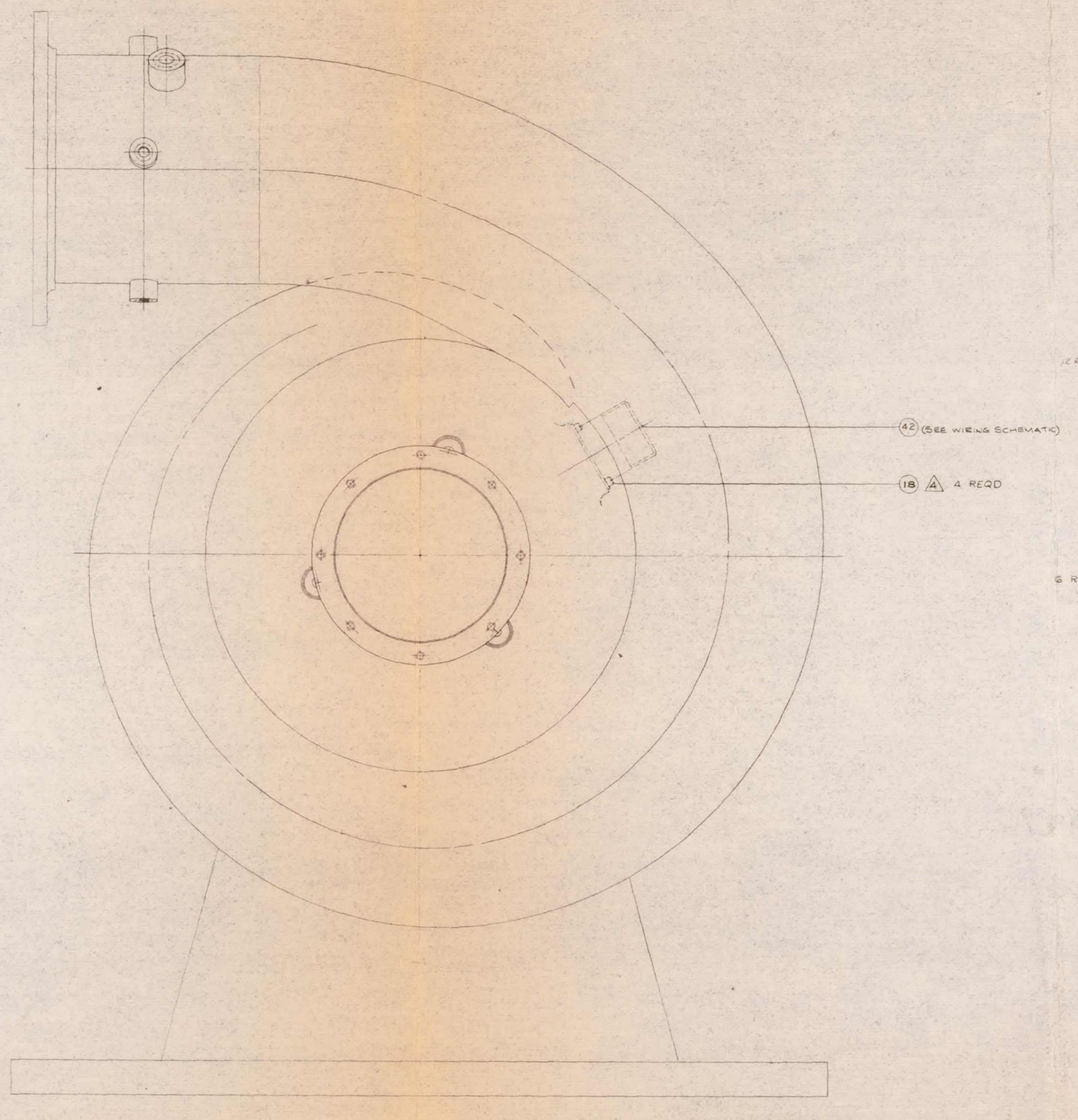
FORM PE5408
DIETZGEN 189W-8

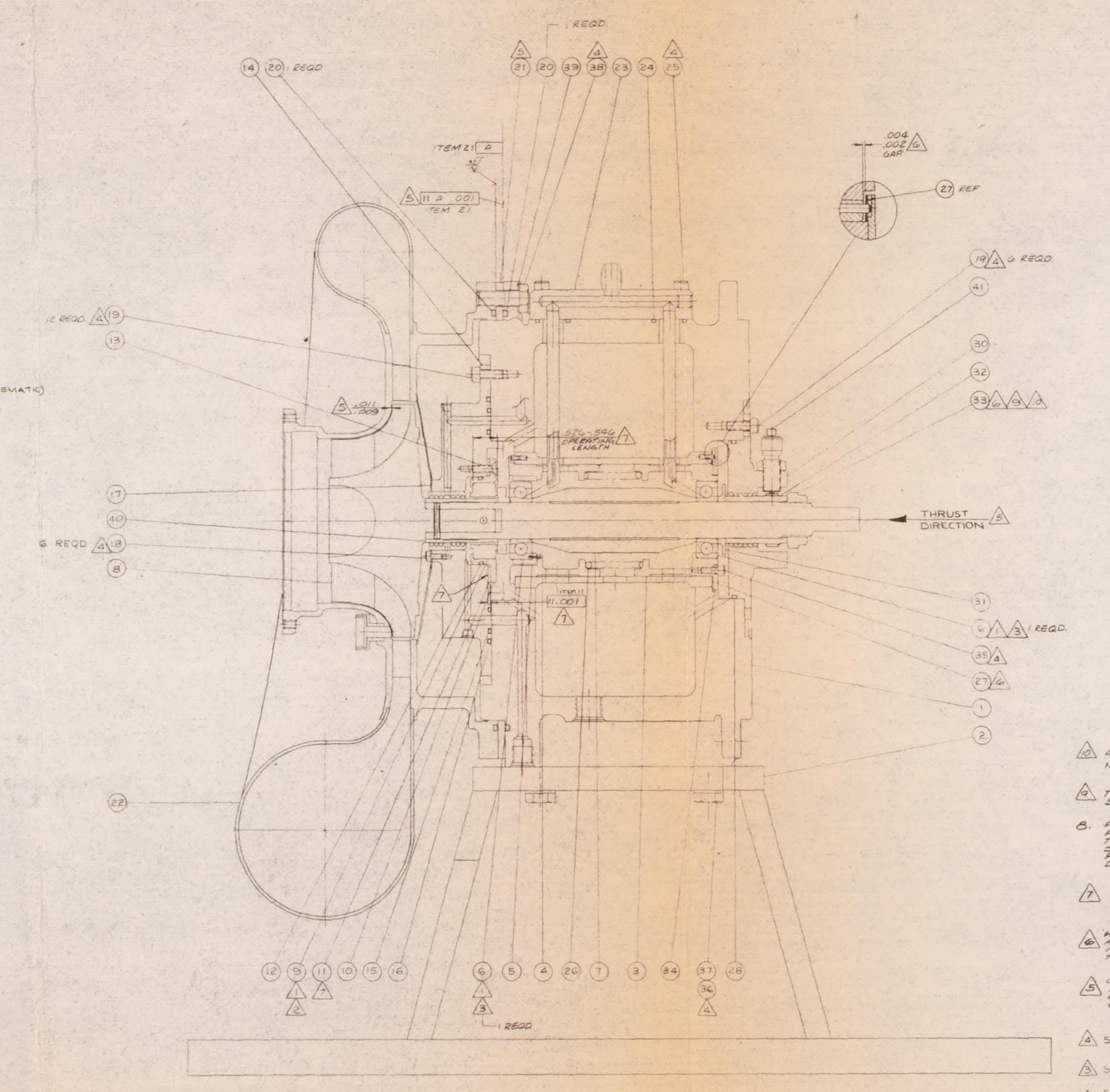
REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ITEM 43 DELETED - SEE E.O.	11-15-67	
	B	DELETED PROPRIETARY BLOCK - SEE E.O	8-29-67	



WIRING SCHEMATIC & PIN LOCATIONS FOR THERMOCOUPLE CONNECTOR (REF ITEM 42)

NOTE: BEARING #1 IS CLOSEST TO TURBINE. ANGLES ARE MEASURED CLOCKWISE LOOKING AT IMPELLER.





10. APPLY 473-010-9001 (1) LUBE TO THREADS OF NOTED ITEMS PRIOR TO ASSEMBLY.

9. TIGHTEN NUT ITEM 33 ON SHAFT ITEM 8, TO 300-350 IN-LBS TORQUE.

8. FOR TORQUE REQUIREMENT ON THREADED FASTENERS SEE AIRESEARCH SPEC AF-349 THE FRICTION TORQUE DEVELOPED FROM SELF-LOCKING DEVICES IS TO BE ADDED TO FASTENER LOADING TORQUE AND MUST BE DETERMINED FOR EACH FASTENER.

7. GRIND ITEM 11 AT ASSEMBLY TO OBTAIN .536 REF OPERATING LENGTH OF SEAL. REMOVE MATERIAL FROM SIDE OPPOSITE PART NUMBER ONLY.

6. WITH THRUST APPLIED IN DIRECTION OPPOSITE OF ARROW, OBTAIN NOTED GAP .002-.004, USING SHIM, ITEM 27. GAP TO BE DETERMINED AFTER TIGHTENING NOTED NUT, ITEM 33, ON SHAFT.

5. USING 10 POUNDS THRUST IN DIRECTION OF ARROW, GRIND ITEM 21 AT ASSEMBLY TO OBTAIN NOTED .009-.011, AXIAL WHEEL CL & DIMENSIONS. REMOVE MATERIAL FROM SIDE OPPOSITE PART NUMBER ONLY.

4. SAFETY WIRE PER MS33540.

3. SEE DRAWING 358500 FOR SPECIAL INSTRUCTIONS

2. SEE DRAWING 699683 FOR SPECIAL INSTRUCTIONS.

1. VENDOR ITEM - SEE APPLICABLE SPECIFICATION OR SOURCE CONTROL DRAWING.

QUANTITY REQD	ITEM NO.	PART NO.	SYM	DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	UNIT WT	ZONE
1	42	223-589-9101	1	CONNECTOR, ELECTRICAL				9
5	41	732-506-9001	1	TRANSDUCER, MOTIONAL PICKUP				5
1	40	699821-1		SPACER, LABYRINTH				8
12	39	AN960C516L		WASHER, FLAT				6
12	38	AN5H-6A		BOLT, MACHINE, AIRCRAFT				6
4	37	AN960C616		WASHER, FLAT				6
4	36	AN6CH10A		BOLT, MACHINE, AIRCRAFT				6
4	35	MS24674-2		SCREW, CAP, SOCKET HEAD				5
1	34	699820-1		RETAINER, BEARING				6
1	33	699936-1		NUT, SELF LOCKING				5
1	32	699819-1		SPACER, SHAFT				5
1	31	699818-1		SLINGER, OIL				5
1	30	699817-1		CARRIER, LABYRINTH				5
1	28	NAS1593-042		PACKING "O" RING				6
AR	27	699816-1,-2,-3		SHIM, BEARING CARRIER				5
1	26	699813-1		SPRING, HELICAL, COMPRESSION				6
4	25	MS24673-5		SCREW, CAP, SOCKET HEAD				6
2	24	NAS1593-016		PACKING O RING				6
1	23	699815-1		NOZZLE ASSEMBLY, RECLASSIFIER				6
1	22	699802-1		SCROLL ASSEMBLY, TURBINE				8
1	21	699814-1		SHIM, SEALING SPACER				6
2	20	NAS1593-174		PACKING "O" RING				6/7
18	19	MS24673-2		SCREW, CAP, SOCKET HEAD				5/8
10	18	NAS1352-C04H4		SCREW, CAP, SOCKET HEAD				8/9
1	17	699812-1		SHIELD, IMPELLER				8
1	16	NAS1593-160		PACKING "O" RING				7
2	15	NAS1593-012		PACKING O RING				7
1	14	699811-1		ADAPTER SEAL, LABYRINTH				7
6	13	MS24693-C28		SCREW, MACHINE, FLAT HD.				8
1	12	NAS1593-031		PACKING "O" RING				7
1	11	699810-1		SPACER, SEAL				7
1	10	699809-1		ADAPTER, SEAL				7
1	9	699683-1		SEAL & ROTOR SET, MATCHED				7
1	8	699803-1		WHEEL ASSEMBLY, TURBINE				8
1	7	699808-1		SPACER, BEARING				6
2	6	358500		BEARING, BALL, THRUST				6/5
1	5	699807-1		MOUNT BEARING, RESILIENT				6
1	4	699806-1		CARRIER, BEARING				6
1	3	699805-1		CARRIER, BEARING				6
1	2	699663-1		STAND ASSEMBLY, MOUNTING				5
1	1	699822-1		HOUSING ASSEMBLY				5
-1	← ASSY			LIST OF MATERIAL				

REQD	NEXT ASSY	USED ON
1(-1)	FINAL	699800-1

HEAT TREATMENT (HARDNESS AND SPEC)	PROCESS (NAME AND SPEC)
	NOTED

~~UNLESS OTHERWISE SPECIFIED ON THIS DRAWING, FABRICATION OF THIS ITEM SHALL BE IN ACCORDANCE WITH AIRESEARCH SPECIFICATION SG-5535, STANDARD DRAWING INTERPRETATIONS~~

SIGNATURES	DATES
DFT	3-24-67
CHK	6-16-67
MFG Q.C. / E. Johnson	5-18-67
MATL	
STRESS C.A. Larson	6-30-67
AERO	5/18/67
APPD	7-26-67
APPD	7-26-67
DESIGN ACTIVITY APPD	7-27-67
OTHER ACTIVITY APPD	

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DWG TITLE: RESEARCH PACKAGE ASSEMBLY, TURBINE

SIZE J | CODE IDENT NO. 99193 | DWG NO. 699801

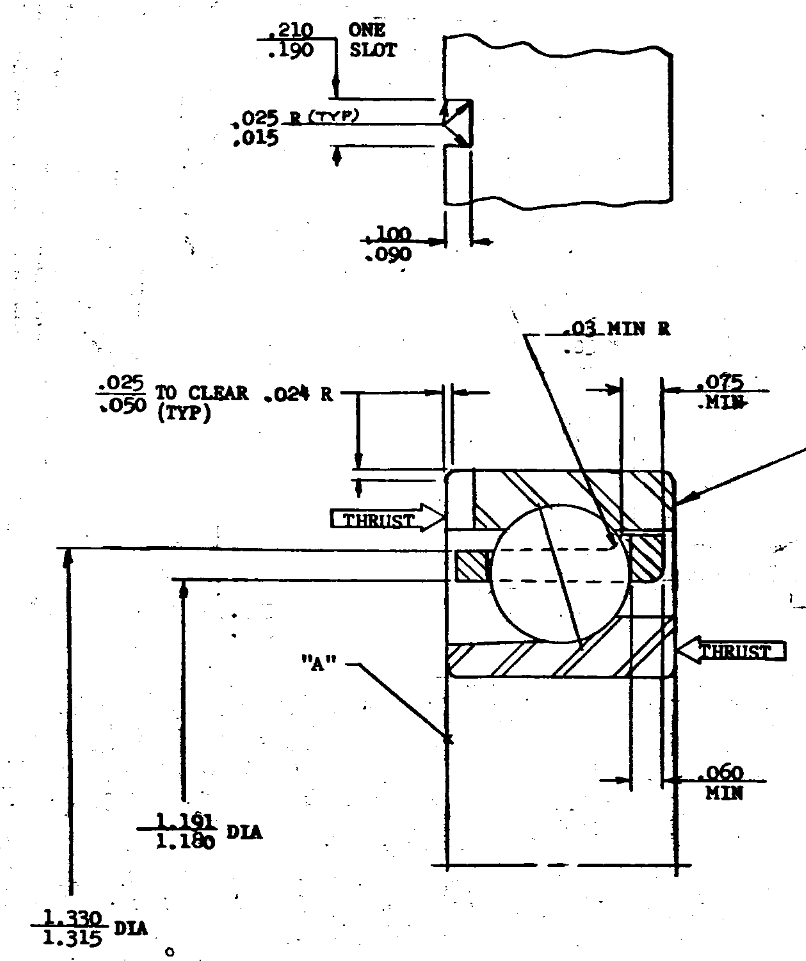
SCALE 1/1 | WT — | SHEET 1 OF 1

699801

PART NUMBER
358500-1

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED
A	ADDED LEADER & ARROWHEAD	6-5-67	R.D.
B	INC. DRN # 18140, SPEC. NOTE WAS: MARK PART NUMBER AND SERIAL NUMBER HERE PER AIRESEARCH SPEC. MC-5014 CLASS II	11/7/67	J.D. [illegible]
C	REVISED SPEC. NOTE WAS: MARK PART NUMBER AND SERIAL NUMBER HERE PER AIRESEARCH SPEC. MC-5014, CLASS II. MARKING ON O.D. OPTIONAL. SEE E.O.	11/10/67	F.J. [illegible]
D	ADDED .025/.015 R (TYP) — SEE E.O.	7/31/68	[illegible]



MARK PART NUMBER AND SERIAL NUMBER HERE PER AIRESEARCH SPEC MC 5014, CLASS II OR III C MARKING ON O.D. OPTIONAL

See tab block (upper left corner) for PART NUMBER

BEARING DESCRIPTION: BALL, ANGULAR CONTACT, 7104		GRADE: AIRESEARCH 5
INNER RING	**OUTER RING**	**ASSEMBLED BEARING CHARACTERISTICS**
MATERIAL: CEVM M-50 PER AMS 6490 Rc 60 MIN	MATERIAL: CEVM M-50 PER AMS 6490 Rc 60 MIN	TOTAL DIAMETRAL (M) CLEARANCE OF (DIAMETRAL, AXIAL) .0013-.0017 UNDER 1 LBS GAGE LOAD
BORE: .7874-.7872 (20 MM) (M) TAPER/FT:	OD: 1.6535-1.6533 (42 MM) (M)	**SPECIAL FEATURES**
WIDTH: .4724-.4624 (12 MM) (M)	FLANGE OD:	1. FACES "A" TO BE FLUSH WITHIN ±.0001 WITH 5 LBS THRUST LOAD APPLIED IN DIRECTION SHOWN.
RACE DEPTH: 20 MIN % BALL DIA	WIDTH: .4724-.4674 (12 MM)	2. PARTS SHALL NOT CHANGE IN DIMENSION IN EXCESS OF .000050 IN/IN AFTER EXPOSURE TO 750°F FOR 10 HOURS.
RACE CURVATURE: 52-53 % BALL DIA	FLANGE WIDTH:	3. SEPARATOR TO BE SILVER PLATED .0005-.002 THICK PER AMS 2412.
SEPARATOR PILOT LAND TO GROOVE RUNOUT: TIR	RACE DEPTH: 18 MIN % BALL DIA	4. CONTACT ANGLE 19° (REF).
SEPARATOR	RACE CURVATURE: 52-53 % BALL DIA	5. SEPARATOR BALL POCKET SURFACES CIRCUMFERENTIALLY FORE AND AFT TO BE AT BEARING PITCH DIAMETER.
MATERIALS: SILICON IRON BRONZE PER AMS 4616	SEPARATOR PILOT LAND TO GROOVE RUNOUT: .0005 TIR	6. HEAT TREATMENT OF CEVM M-50 TO BE PER SPEC H-55.
CONSTRUCTION: MACHINED	**ROLLING ELEMENTS**	7. BEARING TO BE NON-SEPARABLE UNDER NORMAL HANDLING.
ASSEMBLY: ONE-PIECE	MATERIAL: CEVM M-50 PER AMS 6490 Rc 60 MIN	
PILOTING SURFACE: OUTER RING LAND	COMPLEMENT PER ROW: 11-9/32 DIA	
PILOT CLEARANCE: .006-.012	**CLOSURES**	
OPERATIONAL LUBRICANT	NUMBER: NONE	
NAME: OIL, SYNTHETIC, AIRCRAFT GAS TURBINE, LUBRICATING	TYPE: (SHIELDS, SEALS)	
MILITARY SPEC NO.: MIL-L-7808	MATERIAL:	
BEARING PRELUBRICATION: DIP AND DRAIN	CONSTRUCTION:	

PACKAGING PER AIR. SPEC CP-14	PRODUCTION BULK PACK	COMMERCIAL SPARES PACK	MILITARY SPARES PACK
PRESERVATIVE:	MIL-L-6085	MIL-L-6085	MIL-P-197
AIRESEARCH PART NUMBER:	358500 -1	358500 -1	358500 -4

PROCUREMENT PER ASL 358500-

9. (C) DESIGNATES CRITICAL CHARACTERISTIC
(M) DESIGNATES MAJOR CHARACTERISTIC
8. PARTS SHALL CONFORM TO AIRESEARCH SPEC SC-5354
7. PARTS PROCURED BY VENDOR PART NUMBER SHALL BE PROCURED IN ACCORDANCE WITH THIS AIRESEARCH SOURCE CONTROL DRAWING.
6. IDENTIFY PACKAGING WITH AIRESEARCH PART NUMBER.
5. ALL DESIGN AND PART NUMBER CHANGES SHALL RECEIVE PRIOR AIRESEARCH APPROVAL.
4. ONLY THE ITEMS LISTED ON THE ASL AND IDENTIFIED BY VENDOR'S NAMES, ADDRESSES AND PART NUMBERS HAVE BEEN TESTED AND APPROVED FOR USE IN THE END UNIT. A SUBSTITUTE ITEM SHALL NOT BE USED WITHOUT PRIOR TESTING AND APPROVAL BY AIRESEARCH.
3. MILITARY SPARES PACK BEARINGS ARE INTENDED TO FILL MILITARY SPARES ORDERS. BEFORE INSTALLATION, WASH OUT THE PRESERVATIVE AND REPLACE WITH OPERATING LUBRICANT. AFTER THIS OPERATION THE -4 IDENTIFICATION IS CHANGED TO -1 AND THE BEARINGS BECOME INTERCHANGEABLE WITH THE PRODUCTION BULK AND COMMERCIAL SPARES PACK BEARINGS. THEY SHOULD NOT BE USED IN FACTORY INSTALLATIONS BECAUSE OF THEIR RELATIVELY HIGH COST.
2. FOR ECONOMY, PRODUCTION BULK PACK BEARINGS ARE PREFERRED FOR ALL FACTORY INSTALLATIONS. COMMERCIAL SPARES PACK BEARINGS ARE INTENDED TO FILL COMMERCIAL SPARES ORDERS.
1. PRODUCTION BULK AND COMMERCIAL SPARES PACK BEARINGS ARE INTERCHANGEABLE.

UNLESS OTHERWISE SPECIFIED:

CRITICAL ITEM

SATISFACTORY PERFORMANCE OF THE END PRODUCT DEPENDS ON THE INTEGRITY AND RELIABILITY OF THIS SELECTED CRITICAL ITEM. THE GARRETT CORPORATION RECOMMENDS PROCUREMENT FROM THE ORIGINAL SUPPLIER AS SET FORTH IN ASPR 1-313.

SOURCE CONTROL DRAWING	
SIGNATURES	DATES
DFT D.A. [illegible]	1/18/67
CHK R.L. [illegible]	1/21/67
APPD D.E. J[illegible]	1/21/67
APPD	
APPD R.F. [illegible]	2-16-67
DESIGN ACTIVITY APPD B. Elliott	2-16-67
OTHER ACTIVITY APPD	

AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DWG TITLE: BEARING, BALL, THRUST

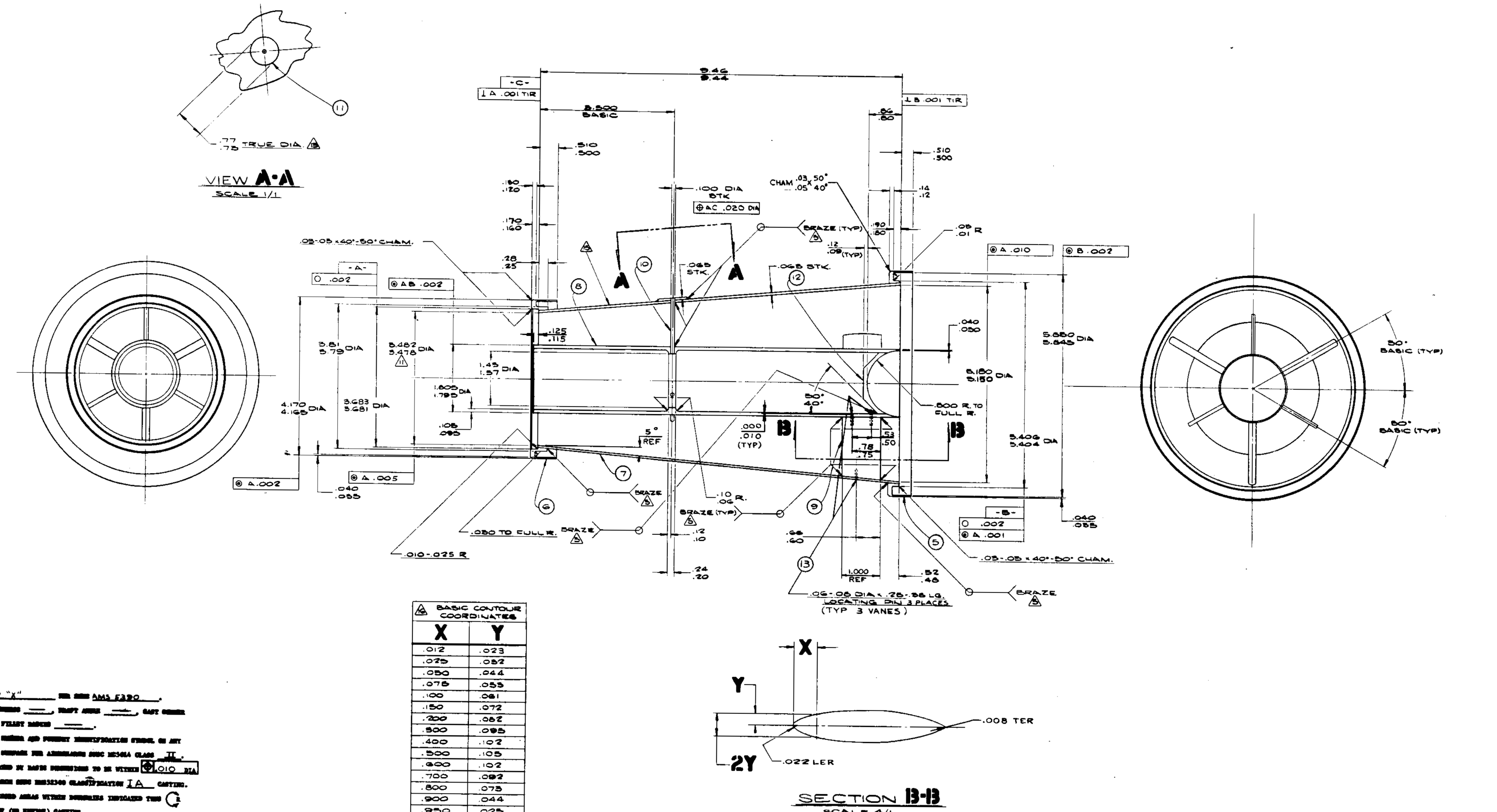
272267

SIZE	CODE IDENT NO.	DWG NO.
C	99193	358500
SCALE NONE	WT –	SHEET 1 OF 1

DWG NO. 358500 REV D

P-5599A—SIMS KBE 1000-M

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



BASIC CONTOUR COORDINATES X	Y
.012	.023
.025	.032
.050	.044
.075	.053
.100	.061
.150	.072
.200	.082
.300	.095
.400	.102
.500	.105
.600	.102
.700	.092
.800	.073
.900	.044
.950	.025
1.000	.002
REF: TEMPLATE LAYOUT L699899	

NOTES:

1. ALL MACHINED SURFACES 125 EXCEPT AS NOTED.

DESIGNATES CRITICAL CHARACTERISTIC
DESIGNATES MAJOR CHARACTERISTIC

3. LOT CONTROL TO BE ESTABLISHED FOR THIS PART. SERIALIZATION TO BE APPLIED BY FABRICATOR OF RAW FORGINGS AND MAINTAINED THROUGHOUT MANUFACTURING AND ASSEMBLY CYCLES AND THEREAFTER.
4. METHOD OF FABRICATION OPTIONAL WITH PRIOR ENGINEERING APPROVAL.
5. FURNACE BRAZE PER AIRESEARCH SPEC. WBS 5027 USING NICKEL BASE BRAZING ALLOY PER AIRESEARCH SPEC EMS 54752 TYPE II GR 2100.
6. PRESSURE TEST FINISHED ASSEMBLY WITH AIR AT 70 PSIG PER AMS 2606.- NO LEAKAGE ALLOWED.
7. LEAK TEST AT ROOM TEMPERATURE. LEAK RATE SHALL BE LESS THAN 1X10-6 STANDARD CC HE/SEC.
8. PENETRANT INSPECT PER AMS 2645.
9. ALL INTERNAL WELD AND BRAZE JOINTS TO FAIR SMOOTHLY.

11. NOTED DIAMETER MAY EXTEND .150 INTO DIFFUSER.

13. FORM ITEM 11 TO MATCH CONTOUR OF ITEM 7.
14. BRAZE FIT .002-.004 TYPICAL.
15. PART NUMBER AND SERIALIZATION PER AIRESEARCH SPEC. MC 5014 CL II.

16.1 MATERIAL HASTELLOY "X" PER SPEC AMS 5390.
CAST WALL AND WEB THICKNESS —, DRAFT ANGLE —, CAST CORNER RADIUS —, CAST FILLET RADIUS —.
16.2 APPLY AIRESEARCH PART NUMBER AND FOUNDRY IDENTIFICATION SYMBOL ON ANY EXTERNAL NON-MACHINED SURFACE PER AIRESEARCH SPEC MC 5014 CLASS II.
16.3 ALL CAST FEATURES LOCATED BY BASIC DIMENSIONS TO BE WITHIN ⊕ .010 DIA
16.4 INSPECTION PER AIRESEARCH SPEC MS 32300 CLASSIFICATION IA CASTING. GRADE B WITH STRESSED AREAS WITHIN BOUNDARIES INDICATED THUS C. GRADE — BALANCE OF (OR ENTIRE) CASTING.
16.5 MAX ALLOWABLE LEAKAGE — CC —/MIN AT — PSIG INTERNAL PRESSURE. INFORMATION PERMISSIBLE PER —.
16.6 HEAT TREAT — PER AIRESEARCH SPEC —. CERTIFIED
16.7 WELD REPAIR PER AIRESEARCH SPEC MS 5013 AUTHORIZED — YES X NO.
16.8 BLEND SHAPE TO FAIR SMOOTHLY BETWEEN POINTS DIMENSIONED IN TABLE
16.9 ALL CONTOUR SURFACES TO BE 80√ AS CAST

QUANTITY REQD	ITEM NO.	PART NO.	SYM	DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	UNIT WT	ZONE
	14							
9	13	-35		PIN		HASTELLOY 'X'/AMS 5754		
1	12	-33		PLUG		HASTELLOY 'X'/AMS 5754		
3	11	-31		DOUBLER		HASTELLOY 'X'/AMS 5536		
3	10	-29		SUPPORT		HASTELLOY 'X'/AMS 5754		
3	9	-27		VANE,		16		
1	8	-25		TUBE, INNER		HASTELLOY 'X'/AMS 5754, 5587		
1	7	-23		TUBE, OUTER		HASTELLOY 'X'/AMS 5536		
1	6	-21		FLANGE		HASTELLOY 'X'/AMS 5754, 5536		
1	5	-19		FLANGE		HASTELLOY 'X'/AMS 5754, 5536		
	4							
	3							
	2							
	1							
-1	← ASSY							

LIST OF MATERIAL

REQD	NEXT ASSY	USED ON
1	699701-1	699700-1

HEAT TREATMENT	PROCESS
NOTED	NOTED

UNLESS OTHERWISE SPECIFIED ON THIS DRAWING, FABRICATION OF THIS ITEM SHALL BE IN ACCORDANCE WITH AIRESEARCH SPECIFICATION SC-5535, STANDARD DRAWING INTERPRETATIONS.

SIGNATURES	DATES
DFT BUSHMAN	9-18-67
CHK	10-3-67
	10-3-67
MATL	11-30-67
STRESS	11-30-67
AERO	11-30-67
APPD	11-30-67
APPD	11-30-67
	12-1-67

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DIFFUSER ASSEMBLY, ANNULAR, TURBINE-BRAYTON ROTATING UNIT

SIZE	CODE IDENT NO.	DWG NO.
E	99193	699899

SCALE 1/1 & NOTED | WT - | SHEET 1 OF 1